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Ernest Owusu Boakye

Essays on Commodity Markets, Macroeconomy and Financial Markets in Developing and Emerging Economies

JYVÄSKYLÄ UNIVERSITY
SCHOOL OF BUSINESS AND ECONOMICS

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ABSTRACT

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This doctoral dissertation studies the relationship between commodity markets, macroeconomy, and financial markets in developing and emerging economies. It focuses on important questions relevant to policymakers and macroeconomists, with a particular emphasis on developing countries, particularly those in Africa, Asia, and Latin America. The dissertation comprises five chapters: an introductory chapter followed by four independent empirical essays. The first three essays employ an empirical analysis based on a constructed theoretical framework, whereas the fourth essay relies primarily on empirical evidence.

The first essay examines the impacts of fluctuations in commodity market prices and terms of trade exposures on the macroeconomic performance of 46 emerging and developing countries (EMDCs) across Africa, Asia, and Latin America. The results indicate that countries in these regions, which heavily rely on commodities, experience significant impacts from fluctuations in global commodity market prices. Moreover, the findings propose that the extent of this exposure varies among countries within the regions and differs when assessing different measures of exposure.

The second essay analyses the relationship between commodity market prices and the global macroeconomy by employing machine learning techniques and a global vector autoregressive (GVAR) approach. By utilising an extensive dataset on individual commodities, the findings propose that only four (4) out of the fifty-five (55) commodities examined have significant implications for the global macroeconomy. Moreover, the findings reveal that advanced economies, such as the Euro Area and other developed nations, as well as China, exhibit considerably stronger exposure to commodity markets compared to emerging economies in Africa, Asia, and Latin America. This observation holds true at both the individual country and regional levels.

The third essay examines the role of "greenflation" within the context of the global economy's transition towards green energy sources. The main findings highlight various factors that contribute to the rise of energy-related commodity prices. These factors include demand chain factors, climate change, and overall inflationary trends. Additionally, the essay reveals that fluctuations in fossil commodity prices have a notable influence on the long-term equilibrium real exchange rate movements for countries such as Norway and Saudi Arabia. Conversely, the renewable energy sector significantly influences the real exchange rates of countries such as Malaysia, New Zealand, Belgium, and South Africa.

The fourth essay focuses on examining the impact of international commodity market prices on some African equity markets, specifically analysing shock and spillover effects. The findings indicate that shocks originating from international commodity markets are transmitted to African equity markets. These results highlight the significant influence of the increasing financialisation of commodity markets in spreading risks to African equity markets.

Keywords: commodity prices, terms of trade, macroeconomy, machine learning, global VAR structural vector autoregression, greenflation, emerging and developing countries.

TIIVISTELMÄ

Boakye, Ernest Owusu
Esseitä hyödykemarkkinoista, makrotaloudesta ja rahoitusmarkkinoista kehittyvissä ja nousevissa talouksissa
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Tämä väitöskirja tutkii hyödykemarkkinoiden, makrotalouden, sekä rahoitusmarkkinan välistä suhdetta kehittyviin talouksiin. Väitöskirjassa keskitytään kysymyksiin, jotka ovat ratkaisevan tärkeitä kehitysmaiden poliittisille päättäjille ja makrotaloustieteilijöille eritysesti Afrikassa, Aasiassa ja Latinalaisen Amerikan alueella. Väitöskirja koostuu johdantokappaleesta, jota seuraa neljä itsenäistä empiiristä esseetä. Kolme ensimmäistä esseetä käyttää empiiristä analyysiä, joka perustuu rakennettuun teoreettiseen viitekehykseen, kun taas neljäs essee on luonteeltaan ensisijaisesti empiirinen.

Ensimmäisessä esseessä tarkastellaan hyödykemarkkinoiden hintavaihteluiden ja -ehtojen vaikutuksia makrotalouden suorituskykyyn 46:ssa nousevan ja kehitysmaiden taloudessa mm. Afrikassa, Aasiassa ja Latinalaisessa Amerikassa. Tulokset osoittavat, että kaikki näiden maiden maat, jotka ovat voimakkaasti riippuvaisia hyödykkeistä, kärsivät merkittävästi raaka-aineiden kansainvälisistä markkinahinnoista. Lisäksi havainnot viittaavat siihen, että tämän laajuudelle altistuminen vaihtelee maittain alueiden sisällä ja vaihtelee eri toimenpiteitä harkittaessa.

Toisessa esseessä analysoidaan hyödykkeiden markkinahintojen suhdetta globaaliin makrotalouteen käyttämällä koneoppimistekniikoita ja globaalia vektoria autoregressiivistä lähestymistapaa (GVAR). Hyödyntämällä suurta tietojoukkoa yksittäisistä hyödykkeistä, havainnot viittaavat siihen, että vain neljällä (4) tutkituista viidestäkymmenestäviidestä (55) hyödykkeestä on merkittäviä vaikutuksia globaaliin makrotalouteen. Lisäksi havainnot paljastavat sen, että kehittyneet taloudet, kuten euroalue ja muut kehittyneet maat lukuun ottaen Kiina, ovat huomattavasti vahvempia hyödykemarkkinoilla verrattuna nouseviin talouksiin Afrikassa, Aasiassa ja Latinalaisessa Amerikassa. Tämä koskee niin yksittäisiä maita kuin alueellista tasoa.

Kolmas essee tarkastelee ”greenflation” roolia globaalissa kontekstissa, eli talouden siirtymistä vihreisiin energialähteisiin. Tärkeimmät havainnot osoittavat, että useat tekijät vaikuttavat energiaan liittyvien hyödykkeiden hintojen nousuun. Näihin tekijöihin kuuluu mm. kysyntä ketjutekijät, ilmastonmuutos ja yleiset inflaatiotrendit. Lisäksi essee paljastaa sen fossiilisten hyödykkeiden hintojen vaihtelulla on huomattava vaikutus pitkän aikavälin tasapainoon Norjan ja Saudi-Arabian kaltaisten maiden reaalikurssimuutoksiin. Toisaalta uusiutuvan energian sektorilla on merkittävä rooli valuuttakurssien ohjaamisesta maissa kuten Malesiassa, Uudessa-Seelannissa, Belgiassa ja Etelä-Afrikassa.

Neljäs essee keskittyy tutkimaan kansainvälisten hyödykemarkkinoiden vaikutusta joidenkin Afrikan osakemarkkinoiden hintoja analysoimalla erityisesti shokki- ja heijastusvaikutuksia. Havainnot osoittavat, että kansainvälisiltä hyödykemarkkinoilta peräisin olevat häiriöt välittyvät Afrikan osakemarkkinoille. Nämä tulokset korostavat merkittävää vaikutusta hyödykemarkkinoiden finanssialisointi riskien hajauttamisessa Afrikan osakemarkkinoille.

Asiasanat: hyödykkeiden hinnat, kauppaehdot, makrotalous, koneoppiminen, globaali VAR-rakennevektorin autoregressio, greenflation, nousevat- ja kehitysmaat

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Helsinki, December 2023
Ernest Owusu Boakye

CONTENTS

1 INTRODUCTION

1.1 Background

> "*Global economic development has long been propelled by the mass production and consumption of raw materials—for food, energy, shelter, and all the comforts of modern civilization. Even as the human population quadrupled over the past 100 years, global commodity markets kept the world well stocked and supported poverty reduction and better living standards*." Baffes and Nagle (2022)

Primary commodities are essential for the welfare of every country. All tangible things are made from a primary commodity, derived either from agricultural products, metals, minerals, or energy resources. According to Baffes and Nagle (2022), commodities are the foundation of global economic development. Consequently, commodity prices play a crucial role in economic planning, growth, and development, especially for emerging and developing countries in Africa, Asia, and Latin America. Any change in commodity prices directly or indirectly impacts commodity-rich resource countries, either benefiting or harming them.

As I write this introduction for my dissertation, it is important to acknowledge that the rising prices of food and energy-related commodities have been further compounded by the simultaneous crises of the COVID-19 pandemic and the Russia-Ukraine war. These occurrences have caused a global economic downturn with significant consequences, particularly for emerging and developing countries (World Bank, 2022).

The asymmetrical impact has been clearly observed in various aspects, such as inflation levels, interest rate hikes, and debt accumulation, particularly in countries across Africa, Asia, and the Latin American region. It has become evident that developments in the global commodity markets have a profound effect on the global economy, especially within emerging and developing countries. Therefore, it is crucial to gain a deeper understanding of the economic consequences arising from fluctuations in commodity market prices. This understanding becomes essential for making informed policy decisions that align with economic objectives, such as promoting growth, maintaining inflation or interest rate stability, and addressing challenges posed by climate change.

The primary objective of this doctoral dissertation is to provide a comprehensive understanding of the various factors influencing commodity market price exposures in emerging and developing countries. The research particularly sheds light on this issue within the context of countries that are primarily reliant on commodity exports or heavily dependent on commodities (UNCTAD, 2019). While the dissertation primarily focuses on commodity-rich emerging and developing nations, it also takes into consideration the exposure of less commodity-rich countries, predominantly the advanced economies (see Figure 1).

Many discussions regarding commodity market prices in relation to the macroeconomy and financial market conditions focus on the impacts of price movements. Theoretically, commodity prices and the macroeconomy are interrelated, either directly or indirectly, through these price movements. Economists, in particular, are often interested in understanding how commodity prices contribute to real economic growth and development, particularly in emerging and developing countries (Kose and Riezman, 2001; Deaton and Miller, 1996). For instance, some economists propose that rising commodity prices directly benefit the gross domestic product (GDP) of commodity-exporting countries. This is attributed to the revenue windfall generated from commodity exports, which can be used to finance domestic absorption [1] encompassing infrastructure, education, and healthcare. Consequently, this financial support contributes to economic growth and development (Deaton and Miller, 1996; Collier and Goderis, 2012; Mendoza, 1997). Conversely, another school of economic thought proposes that increasing commodity prices also boost the currency positions (i.e. the exchange rate) of commodity-exporting countries through foreign exchange earnings (Schmitt-Grohé and Uribe, 2018; Shousha, 2016) and positively impact their terms of trade (Mendoza, 1995). These discussions continue to be active within the current economic discourse, yielding inconclusive observations and debates.

[1] Domestic absorption is the sum of household consumption, private investment, and government expenditure

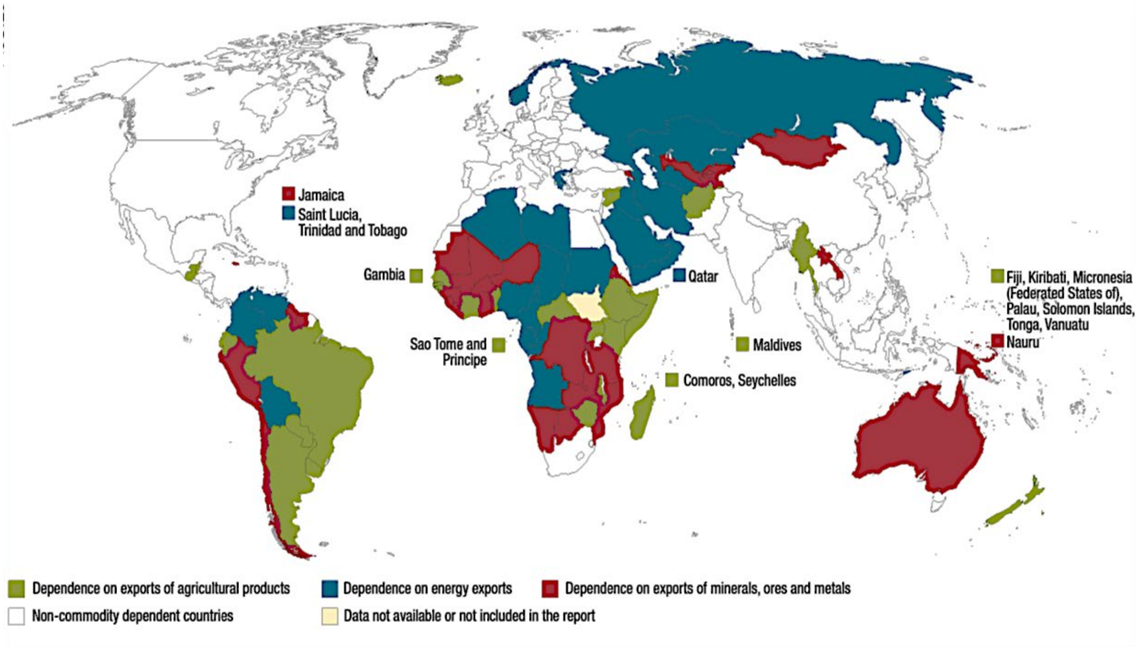

Figure 1. Distribution of commodity-dependent and non-commodity-dependent countries within each commodity group, 2013–2017.

Source: State of Commodity Dependence 2019, UNCTAD

The relationship between commodity market prices, macroeconomy, and financial markets remains an ongoing topic of discussion in economics. This dissertation aims to contribute to this field by conducting a comprehensive study of commodity market price exposures and analysing their economic and financial impacts across various regions. The focus includes emerging and developing countries in Africa, Asia, and Latin America, along with some advanced economies.

The dissertation consists of four empirical essays based on a theoretical framework that explicitly describes the relationships between macroeconomic variables and commodity market prices. Each essay addresses a specific aspect of the topic.

The first essay assesses the commodity market price and terms of trade exposures of the macroeconomy in emerging and developing countries, utilising aggregate commodity price measures for this analysis. The second essay explores the connections between individual commodity prices and the global macroeconomy, utilising disaggregated commodity price measures. Taking a distinct perspective, the third essay examines the role of transitioning from fossil fuels to sustainable energy production, specifically investigating the impact on commodity price inflation (i.e. the rise of commodity prices) and real exchange rate exposures. Lastly, the fourth essay focuses on financial markets and explores the shock and spillover effects of global commodity markets on select African equity markets. Subsequently, in the following subsections, I will provide a brief discussion outlining the topics addressed in each of the essays in more detail.

1.1.1 Commodity market price dynamics

Typically, economists have primarily focused on studying the effects of commodity market price movements on real economic performance. One notable study by Deaton and Miller (1996) proposed that the fluctuations in commodity prices significantly impact the real national income of countries – particularly emerging and developing countries – specialising in commodity exports. Building upon this research, Drechsel and Tenreyro (2018) conducted a further study and proposed that the rising commodity prices in recent decades have propelled some commodity-exporting nations into the league of fast-growing economies. These studies highlight the dual impact of commodity market price developments. Therefore, understanding their effects on emerging and developing economies becomes crucial when informing policy-making processes, particularly in the context of significant global events such as the ongoing COVID-19 pandemic and the Ukraine war. However, it is essential to first explore and shed light on the overall trends and advancements observed in commodity markets over the past few decades.

Notably, the commodity market sector has witnessed fluctuations over the past 30 years, characterised by episodes of both booms and busts[2] (see Figure 2 below). This price volatility has garnered the attention of researchers, scholars, and policymakers since the 1970s. During this period, commodity prices skyrocketed, doubling or even tripling in certain instances, primarily due to the rapid economic transformation in emerging countries such as China. Additionally, the emergence of new commodity producers in regions such as Asia, Africa, and Latin America also contributed to these price increases (World Bank, 2018; Baffes and Nagle, 2022). Moreover, the evolution of commodity market price cycles in recent decades has been far from smooth, as evidenced by the significant upward and downward trends observed in global commodity prices (as depicted in Figure 2). Several factors, including global financial or economic conditions, have played a role in these major price fluctuations. For instance, events such as the 1997–98 Asian financial crisis, the 2008–2009 global economic recession, the COVID-19 pandemic, and the recent Ukraine war have exerted influence on commodity market prices. During these crises, the prices of energy, agricultural products, and metals – the three major sectors in the global commodity market – experienced significant declines following previous periods of growth.

[2] In other words, booms and busts are the periods of rising and falling commodity prices, respectively.

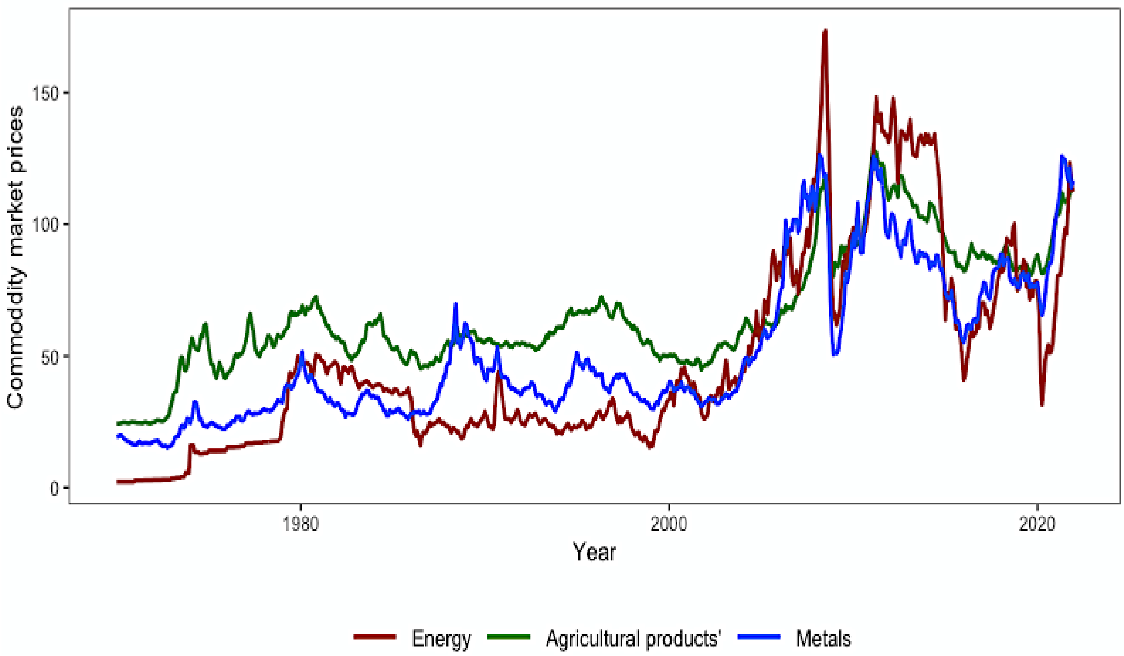

Figure 2. Evolution of commodity market price cycles, 1970m1-2021m12.
Source: Author's calculation based on data from the World Bank's Commodity Market Database 2022

Figure 2 clearly illustrates the volatility of commodity markets from 1980 to 2000, displaying a moderate level of volatility overall. However, subsequent to this period, the volatility increased significantly. For instance, after the Asian financial crisis in 1997–1998, global commodity market prices experienced a substantial surge, reaching a peak in the 2000s. Subsequently, during the 2008–2009 global economic recession, there was a sharp decline in prices. Although there was a quick recovery in prices after 2010 as the global economy improved, it was not as rapid and steep as the surge observed between 2000 and 2007. Moreover, in recent times, commodity markets have been characterised by extreme price volatility and unprecedented swings. This volatility has been amplified by various factors, including the COVID-19 pandemic, the Ukraine war, and associated global economic recessions. These events highlight a clear correlation between commodity market prices and global real economic activity.

However, the correlation between commodity market price movements and global economic activity is not straightforward. Global economic activity may drive commodity prices or vice versa, but the existing economic literature does not provide a conclusive consensus on the matter. One perspective proposes that global economic conditions alone do not fully explain the extreme fluctuations observed in commodity market prices (Jacks and Stuermer, 2020; Céspedes and Velasco, 2012). Another perspective attributes certain price fluctuations to commodity-specific demand and supply shocks (Kilian and Murphy, 2014; Baffes and Kabundi, 2021). More recently, a third perspective has emerged, attributing the heightened volatility in commodity market prices to the financialization[3] of these markets, particularly during the commodity price booms since the early 2000s (Main et al., 2018; Silvennoinen and Thorp, 2013; Henderson et al., 2015). Empirical studies on commodity market price movements have yielded divergent results over the years. However, the aforementioned studies share a common consensus that these movements are influenced by changes in global economic conditions as well as commodity-specific demand or supply shocks. Additionally, the emergence of financial investors treating commodities as an alternative asset class has played a role. It is evident that developments in commodity markets significantly impact all sectors of the global economy, with the intensity of the impact increasing in recent years. For instance, the recent energy price crisis has transmitted inflationary pressures worldwide.

The essays in this dissertation delve into the academic understanding of commodity market price movements and their relationship with global economic activity. In the following section, I outline the theoretical foundation for discussing the role of commodity market prices in relation to macroeconomic activity and financial markets.

1.1.2 Commodity market prices and macroeconomy

In previous studies, the focus of debates on commodity market prices has primarily been on how these price movements impact the macroeconomic performance of emerging and developing countries (Céspedes and Velasco, 2012; Collier and Goderis, 2012; Deaton and Miller, 1996). For instance, a recent study by Baffes and Nagle (2022) revealed that commodity-dependent countries have experienced parallel trends in their macroeconomic performance and commodity price cycles over the span of several decades. According to some discussions, the evidence suggests that commodity exports serve as a crucial source of fiscal revenues for growth and development in emerging and developing countries in the global south (UNCTAD, 2021; Deaton and Miller, 1996). UNCTAD (2021) even suggests that a significant majority of these countries, heavily reliant on commodities, derive a substantial percentage of their revenue, ranging from 20 to 50 percent of their GDP, from commodity exports. Deaton and Miller (1996) propose that if these countries effectively utilize windfall gains resulting from rising commodity prices to finance critical infrastructure such as education, healthcare, transportation, housing, etc., it can significantly contribute to their economic growth and development.

The relationship between commodity market prices and the macroeconomy has intrigued economists who aim to understand how price fluctuations impact the economic performance of commodity exporters and importers in emerging and developing countries. However, the precise transmission mechanism through which commodity prices affect countries remains unclear. One theory

[3] The inflows of private and public investors', speculators' and arbitragers' in the commodity markets who have no interest in the commodity itself but to treat commodities as alternative assets' class in their portfolio

suggests that the impact of commodity market prices on macroeconomic performance can occur through either direct or indirect channels (Barrot et al., 2018; Collier and Goderis, 2012; Raddatz, 2007; Aghion et al., 2009). The direct channel is associated with changes in a country's terms of trade[4], while the indirect channel operates through shifts in macroeconomic variables such as domestic absorption, inflation, and exchange rates (IMF, 2011; Collier and Goderis, 2012). The direct channel is observed when an increase in commodity export revenues, as a proportion of total export revenues, improves the income side of aggregate output (GDP) through a favourable terms of trade balance. Research conducted by Easterly et al. (1993) reveals that shocks in commodity market prices impacting the terms of trade directly influence long-term economic (GDP) growth.

Alternatively, the indirect channel arises from the expenditure side of revenue windfalls resulting from commodity exports. According to Collier and Goderis (2012) and Mendoza (1997), revenue windfalls lead to enhancements in private consumption, private investment, and government expenditure, including the financing of public goods. Another component of the indirect channel, as highlighted by Aghion et al. (2009), involves the inflow of foreign exchange to commodity-exporting countries due to the windfall from commodity export revenues. This inflow often improves the currency positions of these countries in relation to other trading currencies, also known as the valuation of the real exchange rate. Lastly, another indirect commodity channel is the imported inflation, which refers to the rise in prices of domestic consumer goods as a consequence of increasing commodity prices, a phenomenon observed in recent times (Ha et al., 2019).

The impact of commodity market prices on macroeconomic performance has been extensively studied, both theoretically and empirically. A body of research, including works by Broda (2004), Aguiar and Gopinath (2007), Drechsel and Tenreyro (2018), Fernández et al. (2017), Kose (2002), Schmitt-Grohé and Uribe (2018), and Shousha (2016), has examined this relationship. Numerous studies have utilised calibrated real business cycle dynamic stochastic general equilibrium (RBC-DSGE) models, inspired by Mendoza's work (1995), to examine the effects of commodity prices on macroeconomic performance. Mendoza (1995) discovered that changes in the terms of trade, accounting for commodity prices, positively influence economic indicators such as GDP and investments in emerging and developing countries. Similarly, Kose (2002) explored the connection between world trade prices and macroeconomic fluctuations using an RBC model calibrated for primary commodity exporters. His research illustrated the crucial role played by world commodity prices in explaining observed macroeconomic fluctuations in emerging and developing countries.

Several studies have combined both theoretical and empirical approaches to measure the impact of shifts in commodity market prices on macroeconomic

[4] Terms of trade are defined as the relative prices of exports and imports, including commodities.

performance. For instance, Shousha (2016) employed a panel VAR approach and an open economy multi-sector model with financial frictions to explain the effects of commodity market price shocks on the macroeconomic performance of small, open commodity-exporting countries. His findings highlighted the significance of commodity price fluctuations for business cycle fluctuations in both emerging and developing commodity-exporting countries, with particular emphasis on the emerging ones. Additionally, Schmitt-Grohé and Uribe (2018) conducted a study to explore the relationship between empirical and theoretical real business cycle (RBC) models in explaining the fluctuations observed in RBCs within emerging and developing countries. The findings of their research indicated that fluctuations in aggregate output and other macroeconomic variables can be partly explained by changes in commodity market prices. Another relevant empirical study by Fernandez et al. (2017) employed a structural vector autoregressive (SVAR) model to examine the impact of various world trade prices, such as the agriculture price index and terms of trade. Their study revealed that shocks in world trade prices accounted for approximately 33% of the overall fluctuations in aggregate output within individual economies.

Building upon the theoretical and empirical frameworks established by previous researchers such as Shousha (2016), Schmitt-Grohé and Uribe (2018), and Fernandez et al. (2017), this dissertation aims to contribute to the understanding of how commodity market prices influence macroeconomic variables. Initially, I developed a theoretical framework within the context of this dissertation to explain the mechanism through which commodity market prices affect these variables. Subsequently, I implemented the first three essays in an empirical analysis, following the approach adopted by the aforementioned studies. Lastly, the fourth essay focuses on the financial aspects of commodity market interactions and will be discussed in the subsequent section.

1.1.3 Commodity market prices and financial markets

The question of the connection between commodity market prices and financial markets is a subject of interest among both academic researchers in financial economics and financial market practitioners. While discussions with a macroeconomic focus have revolved around the relationship between commodity market prices and overall economic performance, discussions with a financial market focus have centred on the correlations between commodity market prices and specific financial markets, such as stocks and futures. Looking at historical perspectives, it is evident that speculative activity in commodity markets is not a recent development. However, prior to the global economic and financial crisis of 2008–2009, the level of activity in commodity markets was relatively minimal (Erb and Harvey, 2006; Irwin and Sanders, 2011). Gorton and Rouwenhorst (2006) have suggested that the surge in commodity market activity following the crisis is likely attributable to the increased influx of financial or speculative investors who are not primarily interested in the underlying commodities but rather view them as alternative assets for hedging or diversification. This phenomenon is commonly referred to as the financialisation of commodity markets.

According to Main et al. (2018) and Gorton and Rouwenhorst (2006), the attractiveness of commodity market investments for diversification purposes gained more attention from around the year 2000 onwards, and commodity market prices reached all-time highs in 2007. Consequently, the degree of co-movements between commodity markets and the financial sector's volatilities increased. However, Dimpfl et al. (2017) noted that measuring the impact of financialisation is reliant on data and methodological considerations to comprehensively understand the connections. This understanding is crucial to supporting policymakers and investors in their decision-making processes. In the context of the financialisation of commodity markets, several studies have been conducted to examine its impact on equity market prices and volatility (Henderson et al., 2015; Cheng and Xiong, 2014; Main et al., 2018). Haase et al. (2016) propose that the financialisation of commodity markets can affect equity markets through various channels such as returns, volatility, risk premia, and spill-overs in spot or futures markets. Empirical studies by Noor and Dutta (2017), Lin et al. (2014), and Arouri et al. (2011), among others, have tested the impact of financialisation by analysing volatility spillover effects from commodity to equity markets in different countries. These studies indicate that commodity prices have a unidirectional impact on the first and second moments of equity returns in some countries. Building on the work of Haase et al. (2016), other studies have identified bi-directional second-moment connections between equity and commodity market returns (Mensi et al., 2013; Mensi et al., 2017).

In this dissertation, I contribute to the existing literature by assessing the second-moment impact of global commodity markets on equity markets in selected African countries. The focus on African markets is important because there are limited discussions on the financialisation of commodity markets in the African context. Consequently, bridging this research gap is crucial not only for academia but also for policymaking.

1.2 Theoretical framework

Numerous theories have been formulated to explain the influence of commodity market prices on macroeconomic performance and financial markets. Among these theories, the real business cycle (RBC) macroeconomic theory has emerged as the dominant model used to explain the connection between commodity market prices and macroeconomic performance or financial markets. The theoretical framework adopted in this dissertation captures the fundamental aspects of the RBC theory, ensuring a comprehensive understanding without loss of generality. According to the fundamental viewpoint, commodity market prices exert both direct and indirect impacts on macroeconomic indicators, particularly for emerging and developing countries (Kose and Riezman, 2001; Mendoza, 1995). This perspective is based on the fact that these countries, as small, open economies, lack individual market power to influence international commodity prices. Consequently, they experience a high degree of vulnerability to fluctuations in commodity prices due to their reliance on the production and trade of such goods.

In this subsection, I introduce a model that aims to explain the relationship between commodity market prices and macroeconomic indicators. These indicators include real GDP (output), private consumption, private investment, terms of trade, real exchange rate, and inflation (consumer price index). The model explores how these variables interact within both the tradeable and non-tradeable sectors of a representative economy. The framework of the model is based on the well-established neoclassical growth model. It draws inspiration and builds upon previous studies conducted by Schmitt-Grohé and Uribe (2018, 2003), Kose (2002), Mendoza (1995, 1991), and Wickens (2008). By incorporating these specific characteristics into the model, we can gain a deeper understanding of the dynamics underlying the relationship between commodity market prices and macroeconomic indicators in these economies.

The model[5] consists of a representative economy composed of three sectors: exportables *(x)*, importables *(m)*, and non-tradeables *(n)*. This approach allows for the modelling of terms of trade as part of the macroeconomic exposure variables without loss of generality. Within this economy, a representative agent (the household) engages in consumption *(c)*, labour supply *(l)*, and owns firms that produce primary commodities and non-traded goods *(y)*. The economy exports primary goods (part of *y*) and imports intermediate capital goods (i^m). The production sector utilises labour *(l)*, intermediate inputs, and capital *(k)* in the production process. Capital accumulation is permitted, and the rate of capital depreciation is assumed to be uniform across all sectors. Labour is mobile among the sectors, enabling flexibility in workforce allocation. This model represents an economy that is exposed to both productivity shocks and commodity price shocks. To aid in understanding the notation used in the model, the relevant notations are presented in Table 1.

[5] Note: The derivation of the model is also available from the online Appendix of essay number 1 of this thesis

Table 1. Notations of the theoretical model

	Exportables (x)	Importables (m)	Nontradeables (n)
Output	$y_t^x = Q(k^x l^x)$		$y_t^n = Q(k^n l^n)$
Consumption	c_t^x	c_t^m	c_t^n
Capital	k_t^x	k_t^m	k_t^n
Investment	$i_t^x = k_{t+1}^x + (1-\delta)k_t^x$	$i_t^m = k_{t+1}^m + (1-\delta)k_t^m$	$i_t^n = k_{t+1}^n + (1-\delta)k_t^n$
Prices	p^x	p^m	p^n
Consumer price index (CPI)	p_t	p_t	p_t

Households

A representative economy is inhibited by a large number of infinitely lived households with identical preferences who seek to maximize their lifetime utility given by:

$$U(c,l) = E_0\left\{\sum_{t=0}^{\infty}\beta^t \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{l_t^{\gamma}}{\gamma}\right\}, \quad \sigma > 0, \beta > 0, \gamma > 0, \tag{1}$$

where c_t is the aggregate consumption level in the economy consisting of exportable, importable and non-tradeable goods, σ is the degree of risk aversion parameter, l_t is the household labor supply in the economy and γ governs the intertemporal elasticity of substitution in labor supply. The aggregate consumption bundle is given by a constant elasticity of substitution (CES) function, so the consumption function can be written as:

$$c_t = \left(\omega_{TN}^{\frac{1}{\xi}}\left(c_t^{xm}\right)^{\frac{\xi-1}{\xi}} + (1-\omega_{TN})^{\frac{1}{\xi}}\left(c_t^{n}\right)^{\frac{\xi-1}{\xi}}\right)^{\frac{\xi}{\xi-1}}, \quad \xi > 0, \tag{2}$$

where ξ describes the elasticity of substitution between the tradeable (*xm; exports and imports*) and non-tradeable (n) sectors, with ω_{TN} being the weight of the tradeable sector and c_t^{xm} and c_t^n being the household's consumption bundles of tradeable and non-tradeable goods, respectively.

For the tradeable goods consumption, we have:

$$c_t^{xm} = \left(\omega_{T}^{\frac{1}{\zeta}}\left(c_t^{x}\right)^{\frac{\zeta-1}{\zeta}} + (1-\omega_{T})^{\frac{1}{\zeta}}\left(c_t^{m}\right)^{\frac{\zeta-1}{\zeta}}\right)^{\frac{\zeta}{\zeta-1}}, \quad \zeta > 0. \tag{3}$$

Here c_t^{xm} represents the consumption bundle of the tradeables, consisting of exportables (x) and importable (m), while ζ represents the elasticity of substitution between exportable and importable goods in the economy, and ω_T is the respective weight of the tradeable consumption bundle in the economy level consumption basket. Hence, the total consumption expenditure in the economy is given by:

$$p_t c_t = p^x c_t^x + c_t^m + p^n c_t^n, \tag{4}$$

where p_t and c_t are the aggregate price and (real) consumption levels, respectively. For simplicity, we let the price of importable goods serve as the numeraire ($p^m = 1$), which standardizes all prices to be given in terms of the importable goods. This implies that p^{tot}, which denotes the terms of trade, is the price of exportable goods expressed in terms of importable goods. Hence, given the definition for the terms of trade as the relative price of exportable goods in terms of importable goods (see Broda, 2004; Schmitt-Grohé and Uribe, 2018) we have:

$$tot = p^{tot} = \frac{p^x}{p^m}, \quad p^m = 1. \tag{5}$$

Since the model is describing a small, open economy, the decisions of economic agents have no influence on the world prices, and, therefore, the terms of trade p^{tot} is exogenous and taken as given by the economic agents. The same applies to the real interest rate (r_t) that households face when they borrow from or lend to those abroad. To smooth their consumption across time, households are allowed to trade in one-period risk-free bonds denominated in units of the foreign-tradeable goods. Using this normalization, the households maximize their lifetime utility in Eq. (1), subject to sequential budget constraint given by:

$$\begin{aligned} p_t c_t + i_t^{xmn} + \phi_{xmn}(k_{t+1}^{xmn} - k_t^{xmn}) + d_{t+1} &= d_t(1 + r_t) + w_t l_t + R_t^{xmn} k_t^{xmn} \\ i_t^{xmn} &= \Sigma\, i^j, \quad j = x, m, n \\ c_t^{xmn} &= \Sigma\, c^j, \quad j = x, m, n \\ k_t^{xmn} &= \Sigma\, k^j, \quad j = x, m, n, \end{aligned} \tag{6}$$

where i^j, c^j, k^j, w_t and R_t^j denote the private investments, private consumption, capital, real wage rate and real rate of return on capital in sector *j*, respectively. Note that the cost of labor (w_t) is constant across all the sectors, because labor l_t is mobile amongst the sectors and all pay the same wage (w_t) at the steady state optimum. In addition, d_t represents debt (one-period bond) in period *t*, expressed in units of the tradeable composite goods, and r_t denotes the real interest rate on debt held from period *t* to *t + 1*, while ϕ is the capital adjustment cost function[6] assumed to be non-negative, convex and satisfying the condition $\phi_j(0) = \phi_j'(0) = 0$ (see Schmitt-Grohé and Uribe, 2003, 2018). Furthermore, capital accumulation in the economy evolves according to the law of motion as:

$$k_{t+1}^j = (1 - \delta)k_t^j + i_t^j. \tag{7}$$

Using this law of motion to substitute for the investment i^j from the budget constraint, the households maximise Eq. (1), subject to Eqs. (6) and (7), with respect to c_t^j, l_t, k_{t+1}^j, and d_{t+1}. The Lagrangian setup is given by:

$$\begin{aligned} \mathcal{L} = \sum_{t=0}^{\infty} \{ & \beta^t U(c, l) \\ & + \lambda_t \big(d_t(1 + r_t) + w_t l_t + R_t^j k_t^j + (1 - \delta)k_t^j - p_t c_t - k_{t+1}^j \\ & - \phi_j\big(k_{t+1}^j - k_t^j\big) - d_{t+1}\big) \}, \qquad for\ j = x, m, n. \end{aligned} \tag{8}$$

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[6] Schmitt-Grohé and Uribe (2003) suggested that including the capital adjustment cost in a small open economy model ensures that there is a limit to excessive investment volatility induced by variations in the foreign and local interest rate differential. The restrictions imposed on the adjustment cost are also supposed to ensure that the non-stochastic steady state adjustment cost is zero and the domestic marginal rate of interest is equal to the capital net depreciation rate

The first order optimality condition for household consumption implies that the relative consumption between the tradeable and non-tradeable sectors is a function of their relative prices, so based on Eqs. (2) and (3), we have

$$c_t^x = \omega_T \left[\frac{p_t^x}{p_t^{xm}}\right]^{-\zeta} c_t^{xm}, \text{ and } c_t^m = 1 - \omega_T \left[\frac{1}{p_t^{xm}}\right]^{-\zeta} c_t^{xm},$$

where p_t^{xm} is the aggregate price in the traded sector (exports and imports) given by:

$$p_t^{xm} = \{\omega_T (p_t^x)^{1-\zeta} + (1-\omega_T)(p_t^m)^{1-\zeta}\}^{\frac{1}{\zeta-1}}. \tag{10}$$

For the aggregate consumption in the economy, we have:

$$c_t^{xm} = \omega_{TN} \left[\frac{p_t^{xm}}{p_t}\right]^{-\xi} c_t \text{ , and } c_t^n = 1 - \omega_{TN} \left[\frac{p^n}{p_t}\right]^{-\xi} c_t, \tag{11}$$

where p_t is the price of the aggregate consumption in the economy or the implied consumer price index (CPI) given as:

$$p_t = \{\omega_{TN} (p_t^{xm})^{1-\xi} + (1-\omega_{TN})(p_t^n)^{1-\xi}\}^{\frac{1}{\xi-1}}. \tag{12}$$

The economy's traded goods sectors generate (net) foreign exchange income via exporting goods and importing intermediate capital and non-capital goods valued in foreign currency for consumption. This implies that the foreign consumer price index p_t^* consists of the weighted average prices of the trading partners in the economy given as:

$$p_t^* = \left\{\omega_{TN} \left(\epsilon_t {p^*}_t^{xm}\right)^{1-\xi} + (1-\omega_{TN})\left(\epsilon_t {p^*}_t^{n}\right)^{1-\xi}\right\}^{\frac{1}{\xi-1}}, \tag{13}$$

where ϵ_t is the nominal exchange rate. We define the real effective exchange rate (er) in the economy as a ratio of the foreign consumer price index (p_t^*) to the domestic consumer price index (p_t) (see Broda, 2004; Schmitt-Grohé and Uribe, 2018;), so

$$er_t = \frac{\epsilon_t p_t^*}{p_t}. \tag{14}$$

Furthermore, the marginal rate of substitution between the labor supply and aggregate consumption is given by:

$$c_t^\sigma l_t^{\gamma-1} = \frac{w_t}{p_t}, \tag{15}$$

and the household's intertemporal Euler equations are given by:

$$c_t^{-\sigma}\left[1 + \phi_j\left(k_{t+1}^j - k_t^j\right)\right] = \beta E_t c_{t+1}^{-\sigma}\left[R_{t+1}^j + (1-\delta) + \phi_j\left(k_{t+2}^j - k_{t+1}^j\right)\frac{p_t}{p_{t+1}}\right], \quad j = x, m, n \tag{16}$$

and

$$c_t^{-\sigma} = \beta E_t c_{t+1}^{-\sigma}\left[(1+r_t)\frac{p_t}{p_{t+1}}\right]. \tag{17}$$

Hence, the aggregate level of consumption in the economy depends on expectations of future aggregate consumption, changes in the consumer price index (i.e., inflation), the real rate of return on capital, the real interest rate, and the cost of adjusting capital stock in the economy.

Firms

In this model economy, firms engage in trade by producing tradeable (x, m) and non-tradeable (n) goods using capital (k) and labor (l) inputs. The sectoral firms produce their outputs (y_t) using Cobb-Douglas production functions that we assume to be increasing, concave and homogenous of degree one, that is:

$$y_t^{xm} = A_t p^{tot} Q(p^x (k_t^x)^{1-\alpha x}(l_t^x)^{\alpha x} + (k_t^m)^{1-\alpha m}(l_t^m)^{\alpha m}) \tag{18}$$

$$y_t^n = A_t Q\left(p^n (k_t^n)^{1-\theta n}(l_t^n)^{\theta n}\right), \tag{19}$$

where p^{tot} (terms of trade) is the relative price of exportable (x) goods in terms of importable (m) goods. p^n is the relative price of non-tradeable goods. A_t is the productivity shock that affects all sectors in the economy, and α and θ are the shares of output in the tradeable and non-tradeable sectors, respectively.

Profits of firms producing exportable, importable and non-tradeable goods are given by:

$$y_t^j - R_t^j k_t^j - w_t l_t^j, \; j = x, m, n. \tag{20}$$

The firm's first order condition of profit maximization implies that the factor prices should be equal to marginal productivity of capital and labor in the sectors in the optimum, so:

$$R_t^x + (1-\delta) = (1-\alpha x) p_t^x \frac{y_t^{xm}}{k_t^x} \tag{21}$$

$$R_t^m + (1-\delta) = (1-\alpha m) \frac{y_t^{xm}}{k_t^m} \tag{22}$$

$$R_t^n + (1-\delta) = (1-\theta n) p^n \frac{y_t^n}{k_t^n} \tag{23}$$

$$w_t = \alpha x \frac{y_t^{xm}}{l_t^x} \tag{24}$$

$$w_t = \alpha m \frac{y_t^{xm}}{l_t^m} \tag{25}$$

$$w_t = \theta n \frac{y_t^n}{l_t^n}. \tag{26}$$

One of the main features of our empirical analyses is that we assume that the economy is first of all exposed to the productivity shock*s* A_t, but even more importantly, since we are analyzing a set of emerging and developing small, open economies that are supposedly highly exposed to the world market price shocks, we focus specifically on the role of exogenous world market prices, i.e. the terms of trade, the commodity terms of trade, and the global commodity market price index. In the theoretical model, all these shock variables are assumed to be generated by stationary AR (1) processes, so:

$$A_t = \rho_a A_{t-1} + \varepsilon^a, \quad \varepsilon^a \sim N(0, \sigma_a^2) \tag{27}$$

and

$$p_t^i = \rho_i p_{t-1}^i + \varepsilon^i, \quad \varepsilon^i \sim N\left(0, \sigma_i^2\right), \tag{28}$$

where i = (*tot, ctot, gcp*), refers to the standard terms of trade, the commodity terms of trade and the global commodity market index, respectively.

Competitive equilibrium
In the equilibrium, aggregate demand for tradeable and non-tradeable goods in the sectors must be equal to final aggregate tradeable and non-tradeable outputs in the sectors of the economy given by:

$$c_t^{xm} + i_t^{xm} + \phi_{xm}(k_{t+1}^{xm} - k_t^{xm}) = y_t^{xm} \tag{29}$$

and

$$c_t^{n} + i_t^{n} + \phi_{n}(k_{t+1}^{n} - k_t^{n}) = y_t^{n} \tag{30}$$

However, the model economy is a small, open economy that engages in international trade, which consists of importable and exportable primary commodities and final and intermediate goods in the three sectors. Hence, we have the aggregate import expenditures and export revenues in the economy defined as:

$$m_t^* = m_t \; and \; x_t^* = \; p^x x_t, \tag{31}$$

where $p^m = 1$, which, given A.31, the international trade position, i.e., the trade balance in the model economy, is:

$$tb_t^{xmn} = \; x_t - m_t \,. \tag{32}$$

In addition, households in the model economy are allowed to trade in one-period risk-free bonds (d_t) to smooth consumption. Combining Eqs. (32) with (7), (20), (29) and (30), yields the economy-wide resource constraint in the equilibrium to be given as:

$$p_t c_t + i_t^{xmn} + \phi_{xmn}(k_{t+1}^{xmn} - k_t^{xmn}) + d_{t+1} = d_t(1 + r_t) + y_t^{xmn} + tb_t^{xmn}\,, \tag{33}$$

where p_t is the implied CPI defined by Eq. (12), and the foreign CPI p_t^* in the economy is defined by Eq. (13). As explained earlier in connection to Eq. (14), the ratio of the foreign CPI to the domestic consumer price index is the real effective exchange rate (er_t) in the economy. In the steady state equilibrium, we assume that the endogenous labor supply (l) and the sectoral wages (w) are constant. In addition, in the steady state, we assume that r_t is constant.

Therefore, a competitive equilibrium is the economy's set of optimal decisions for $\{c_t, k_{t+1}^{xmn}, d_{t+1}, l^{xmn}, \lambda_t\}$, based on the economy's sectoral prices $\{R_t^{xmn}, w, p_t^{xn}\}$, and given that capital evolves based on equation 7, we have:

a) The consumer optimality condition satisfied
b) The firm's optimality condition satisfied
c) The productivity shock and the exogenous prices follow a stationary AR (1) process based on Eqs. (27) and (28)
d) The market clearing conditions were satisfied based on Eqs. (29), (30) and (33) and the sum of total hours available to labor (l^j) and leisure (l^*).

Based on the theoretical model, I analyze empirically the functioning of this theoretical model, focusing on the role of different price measure (p_t^i), i.e. the commodity terms of trade, commodity market price index, and standard terms of trade (that is, the relation between import and export prices) in affecting the aggregate output (y_t), private consumption (c_t) and investments (i_t), trade balance (tb_t) , CPI (CPI/inflation) and the real exchange rate (er_t). I do not analyze the endogenous labor (l) supply, and the one-period risk free bond (d_t) because the model assumes that, in the equilibrium, they are constant and do not vary over the business cycle. The first three essays are implemented based on this theoretical framework, and I have employed various empirical methodologies often used in the previous literature to investigate the impact of commodity prices on macroeconomic performance of emerging and developing market economies, including advanced economies too.

1.3 Outline of the dissertation

1.3.1 Research questions

The objective of this dissertation is to investigate the impact of commodity market prices on macroeconomic performance, and financial markets in emerging and developing countries. The following research questions, which are related to the issues previously discussed in sections 1.1.2 - 1.1.3, are presented in this dissertation. In section 1.4, a detailed overview of the essays and their contributions to the literature is presented. The summary research questions addressed in each essay are structured according to the following chapters:

Chapter 2

- What impact do the commodity market prices have on the overall macroeconomic performance of developing and emerging countries that heavily concentrate on the production and exports of commodities in Africa, Asia, and the Latin America?

Chapter 3

- What is the connection between the prices of globally traded commodities and global macroeconomy?
- Among the many commodities traded globally, which one or ones are the most important for global economic activities, and what are their impacts on economic development in different regions?

Chapter 4

- What impact does the global transition towards sustainable energy production have on commodity market prices?
- What economic significance do the commodity market prices have on the real exchange rate of commodities-producing countries?

Chapter 5

- What impact does the financialization of commodity markets have on African equity markets?
- In which direction do the transmissions of shocks and volatility go between the relevant markets?

1.3.2 Research methods

The essays in this dissertation have been implemented with an empirical approach, utilising a theoretical framework outlined in Section 1.2. Many studies that explore the connections between commodity market prices, the macroeconomy, and financial markets often rely on different empirical models, such as structural, time series, or panel regression methods. In alignment with these practices, this dissertation also involves the application of these structural models as well as of time series and panel regression analyses in the essays.

The first empirical essay in Chapter 2 is implemented following the theoretical framework explained earlier. To conduct this analysis, a similar approach is employed, as seen in studies by Fernández et al. (2017), Schmitt-Grohé and Uribe (2018), and Shousha (2016). These studies also combined theoretical concepts and empirical methods to examine the relationship between commodity market prices and the macroeconomy. In particular, the structural vector autoregression (SVAR) method is used to simulate short-term effects such as impulse response functions (IRFs) and forecast error variance decomposition (FEVD). However, it is important to note that the econometric specifications of SVAR can only capture short-term interactions among economic variables. To account for long-term interactions, a panel regression technique is employed, specifically the autoregressive distributed lag (ARDL) model. This estimation technique is based on the assumption that the main macroeconomic variables may have a long-run steady-state relationship with the measures of commodity market prices.

In the second essay of Chapter 3, a combination of structural and time series methods was employed to examine the relationship between commodity market prices and the global macroeconomy. The time series method utilised in the study is based on machine learning estimation techniques. Additionally, a global vector autoregression (GVAR) model, which is closely aligned with the theoretical framework, was adopted. The objective of this study was to uncover the interconnectedness between commodity market prices and the global macroeconomy. To achieve this, a global model was used as an alternative to the SVAR (structural vector autoregression) approach. This choice allowed for the inclusion of global variables in the analysis. The GVAR methodology represents a relatively new approach to macroeconomic modelling, combining time series and structural analysis techniques. It enables the assessment of a wide range of economic and financial challenges, spanning from policy analysis to risk management. Notably, the GVAR model has been employed in various other studies, including those conducted by Chudik and Fidora (2012) and Boschi and

Girardi (2011). Initially introduced by Pesaran, Schuermann, and Weiner (2004), and Dées, di Mauro, Pesaran, and Smith (2007).

In the last two essays, I utilised time series econometric methods to analyse the data. In the third essay, presented in Chapter 4, I employed a simple ordinary least squares (OLS) estimation method and panel autoregressive distributed lag (ARDL) methods. These methods enabled me to estimate the long- and short-run impacts of the transition towards sustainable energy production on rising commodity prices and real exchange rate exposures. Moving on to the final essay in Chapter 5, I used the VAR-GARCH and DCC-GARCH models to examine the transfer of conditional volatility and shocks in the commodity markets to equity market returns and volatility in selected African countries. The examination of shocks and volatility transfers has been extensively researched using various conditional correlation models, such as VAR-GARCH and DCC-GARCH models (Arouri et al., 2011; Noor and Dutta, 2017; Mensi et al., 2013), due to their effectiveness in exploring volatility spillovers and time-varying conditional interdependences.

1.3.3 Data

In this dissertation, I have utilised data from a variety of sources. The data used in the essays is not limited to a specific timeframe or raw data format. Instead, I have processed them into a more suitable format for ease of modelling. Additionally, whenever necessary, I have derived new measures that align with the research objective or question. The primary sources of data used in the essays include the World Bank's World Development Indicators (WDI), the International Monetary Fund (IMF), International Financial Statistics (IFS), the United Nations Conference on Trade and Development (UNCTAD), and Thomson Reuters EIKON DataStream.

In research studies, it is common to utilise a variety of measures for commodity prices along with various macroeconomic or financial data sources. Economists generally incorporate macroeconomic variables such as gross domestic product (GDP), consumption, investments, trade balances, consumer price indices, and exchange rates to examine the relationships between commodity market prices and macroeconomic factors. These variables are typically standardised and measured consistently across numerous empirical studies, regardless of the data source or time duration. Financial economists, alternatively, often analyse spot, futures, or forward financial market price data when studying commodity markets. The choice of using spot or futures market data may depend on the specific research question or objective. Nonetheless, unlike macroeconomic data, spot or futures market data is often not standardised. It can vary based on factors such as time, contractual agreements, financial instruments, or the specific exchange being considered. In many cases, the transformations applied to spot or futures market data in financial economic studies are driven by the statistical methods employed or the research objectives pursued.

Conversely, commodity market data is typically denominated in a single currency, predominantly the US dollar, across international markets. While the measurement of commodity market data may differ based on its source, it is typically categorised either by individual items or groups, such as indices. Various commodity groups exist, including agricultural products, precious metals, base metals or minerals, and energy. Table 2 provides an illustration of some commodity categories within subgroups, sourced from the IMF database.

In the first empirical essay, I utilised a dataset containing macroeconomic variables as described in Section 1.2. The dataset covers the time period from 1980 to 2017. Specifically, I obtained annual macroeconomic data on GDP, private consumption, private investments, trade balance, consumer price index, and exchange rate from the World Bank WDI database. The primary commodity market data employed consisted of observations on commodity terms of trade and general commodity price indexes. The commodity terms of trade were measured as a GDP-weighted ratio of commodity export prices to import prices, as originally formulated by Gruss and Kebhaj (2019). For the second essay, I utilised individual commodity market data along with data on three macroeconomic variables: GDP, exchange rate, and inflation. The individual commodity market data was sourced from the IMF primary commodities database (see Table 2 for more details). In the third and fourth essays, both subgroup and individual commodity-level time series data were utilised. Additionally, equity market time series data from different sources was incorporated into these studies. Furthermore, the essays provide additional details on the formation of the analysed variables and their respective data sources.

Table 2. Primary commodities classified in groups

Vegetable oils	Cereals	Meats and sea food	Beverages	Raw materials	Others
Rapeseed Oil	Wheat	Beef	Coffee	Soft Sawnwood	Groundnuts
Olive Oil	Rice	Swine Meat	Tea, Kenyan	Hard Sawnwood	Corn
Palm Oil	Barley	Poultry	Cocoa	Soft Logs	Fertilizer
Sunflower Oil	Sorghum	Lamb		Hard Logs	Orange
Soybeans Oil	Oats	Shrimp		Cotton	Sugar
Soybeans		Fish		Rubber	Timber
Soybean Meal				Softwood	Wool
				Hardwood	Bananas
Precious metals	Base metals	Energy			Potassium Fertilizer
Gold	Lead	EU Natural Gas			D. phosphate
Silver	Copper	US Natural Gas			Tomato
Palladium	Iron Ore	Brent Crude			
Platinum	Nickel	Dubai Crude			
	Aluminium	WTI Crude			
	Zinc, Cobalt	Coal			
	Tin, Uranium,				

Source; IMF primary commodity database (2021)

1.4 Overview of the essays

The first three essays covered in Chapters 2 to 4 were collaboratively authored with Professors Juha Junttila and Kari Heimonen. Serving as the main author, I assumed responsibility for various aspects, including writing, formulating the research problem, conducting the literature review, developing the theoretical framework, performing econometric estimations, retrieving and analysing data, with additional contributions from Professors Juha Junttila and Kari Heimonen. They played a role in the conceptualization, analysis of results, language editing, providing comments and suggestions for improvement, as well as providing guidance for publication. The last essay presented in Chapter 5 was authored solely by me. In this essay, I took charge of the writing, modelling, data retrieval and analysis, and econometric estimations, as well as presenting the results and discussion.

1.4.1 Essay 1: Assessing the Commodity Market Price and Terms of Trade Exposures of Macroeconomy in Emerging and Developing Countries

The Chapter 2 of the dissertation closely adheres to the previously discussed theoretical framework as it aims to empirically investigate the impact of commodity market prices and terms of trade exposures on emerging and developing countries. This essay, co-authored by Professors Juha Junttila and Kari Heimonen, serves as the foundation for the overall dissertation and focuses on examining the commodity market exposures of countries in Africa, Asia, and Latin America. To achieve this, the essay utilises annual data on six macroeconomic variables and commodity market prices, spanning the period from 1980 to 2017. By employing this data and empirical methodology, we are able to explore the effects of commodity prices and terms of trade fluctuations on the macroeconomic performance of 46 emerging and developing countries across Africa, Asia, and Latin America.

The essay makes a novel contribution to the existing literature in several ways. Firstly, unlike previous studies, we acknowledge that individual macroeconomic variables in EMDCs (Emerging Market and Developing Countries) are exposed differently to the effects of commodity market prices. Therefore, it is incorrect to consider these countries as a homogenous group, as many other studies have assumed (e.g. Céspedes and Velasco, 2012; Kose and Riezman, 2001; Deaton and Miller, 1996). Additionally, based on our theoretical framework, this study identifies a common long-run, stationary relationship between all individual macro variables and the three price measures introduced in our model. this finding holds notable significance and represents a novel contribution in the context of EMDC data. It emphasises the strong price effects of global commodity markets on diverse economic indicators, such as output, consumption, investment, trade balance, inflation, and exchange rate exposure.

The second contribution of this study to the existing literature lies in its examination of short-run shock impacts. We introduce the standard terms of trade exposure, which show that non-commodity market price effects are transmitted through the composition of non-commodity exports and imports, such as services, for EMDCs. This aspect sheds new light on the complex relationship between commodity prices and the overall economy. Lastly, our essay recognises that many developing countries heavily rely on a small range of commodities for their exports or imports. Consequently, the utilisation of individual commodity price measures, such as minerals, energy, or agricultural products, for all countries may inadequately capture the country-specific effects. Our estimation takes this limitation into account, thereby leading to a more accurate understanding of the effects of commodity prices on each country.

In summary, this study utilised structural and dynamic panel data models to examine the response of macroeconomic variables in EMDCs to commodity market price shocks, both in the short and long run. The results revealed a strong connection between these emerging and developing countries and the fluctuations in global commodity prices, particularly in regions such as Africa, Asia, Latin America, and the Caribbean. However, it is important to note that the

EMDCs cannot be considered a homogeneous group with respect to their exposure to commodity market fluctuations. Our findings reveal significant differences in the extent of exposure among countries, regions, and different commodity groups. Despite the disparities, a common characteristic across all these countries is the significant impact of commodity prices on their macroeconomic variables. This implies that changes in commodity prices have considerable repercussions on the economic conditions and performance of these countries.

1.4.2 Essay 2: Commodity Markets and the Global Macroeconomy: Evidence from Machine Learning and GVAR

Numerous studies have been conducted to examine the impact of commodity market prices on the global macroeconomy (Bettendorf, 2017; Chudik and Fidora, 2012; Boschi and Girardi, 2011; Cashin et al., 2014). However, these studies often encounter a research gap due to the use of a somewhat arbitrary selection of commodities or commodity groups based on subjective judgements of their importance for global practical analysis or for forecasting purposes. The essay presented in Chapter 3, co-authored by Professors Juha Junttila and Kari Heimonen, aims to bridge this research gap. By employing machine learning techniques, we aim to identify the subset of globally traded commodities that exhibit the strongest predictive power for global macroeconomic activity.

To conduct this analysis, a quarterly dataset spanning from 1990 Q1 to 2019 Q4 is utilized. This dataset examines the interconnections between commodity market prices and the global macroeconomy. The essay presents a novel contribution to the existing literature on commodity market prices and global macroeconomic interactions. It achieves this by employing a large dataset encompassing individual commodities without any predetermined assumptions or ad-hoc selections based on their perceived importance to the global economy. Furthermore, the study utilises machine learning techniques capable of handling high-dimensional datasets to identify and unveil globally traded commodities with the highest predictive power on global macroeconomic activity. This approach distinguishes it from previous studies that often relied on subjective reasoning to selectively analyse only a few commodities. In contrast, the essay aims to provide a comprehensive analysis by considering a broad range of potential globally traded commodities. Moreover, the study incorporates a GVAR model, which combines country-level time series data, panel data, and factor analytic techniques. This enables us to assess the consequences when a unit shock affects the globally identified most important commodity markets. Additionally, the model facilitates an examination of the transmission of these shocks among various countries and groups, including Africa, Asia, the Euro area, Latin America, and the Middle East, as well as individual major economies such as the UK, China, and the US.

In summary, the empirical findings presented in Chapter 3 demonstrate that the degree of commodity market price exposure is more pronounced among advanced economies, such as the Euro area, China, and other developed countries. Conversely, emerging economies in Africa, Asia, and Latin America exhibit smaller effects at both the country and regional levels. These findings indicate that the impact of commodity market price shocks on macroeconomic performance varies significantly depending on the specific commodity and country in question. Moreover, the relative importance of certain essential commodity market price shocks can also change over time. Overall, the evidence suggests that the influence of commodity market prices on the global macroeconomy is not consistent across different commodities, countries, or the macroeconomic variables analyzed.

1.4.3 Essay 3: Greenflation, Renewable and Fossil Commodity Currencies

Inflation has surged in the global economy following the pandemic years of 2020–2021, significantly surpassing the target levels set by the central banks. This inflationary surge can be attributed, in part, to various policies implemented to reduce greenhouse gas emissions. Furthermore, the process of decarbonisation has become more expensive, with costs closely linked to commodity prices, especially those related to the production of fossil and renewable energy sources (Mier and Weissbart, 2020). The impact of the inflation crisis related to commodities is experienced worldwide, but its magnitude may vary across countries based on their production structures. The essay presented in Chapter 4 examines the impacts of the transition towards sustainable energy production on commodity price inflation (i.e. rising commodity market prices) and the real exchange rate of 26 emerging and advanced countries.

The essay focuses on examining the factors contributing to the increasing prices in the commodity market, specifically within the metal-mineral sector. It utilises a simple time series regression method for this analysis. Moreover, the paper explores the impact of both energy (fossil) and metal-mineral (renewable) commodity prices on the currencies of 26 different countries. Several previous studies, including those conducted by Ricci et al. (2013), Cashin et al. (2004), and Chen and Rogoff (2003), among others, have also investigated the correlation between commodity market prices and the currencies of commodity-producing countries. These studies have found evidence suggesting that the real exchange rates of certain commodity-producing countries exhibit a long-run steady-state equilibrium relationship with commodity market prices. Consequently, the currencies of these countries can be classified as commodity currencies.

This essay makes an important contribution to the existing body of research by focusing on the sub-sectors of commodity market prices, specifically dividing them into fossil energy (natural gas and oil) and renewable energy (metals and minerals). The findings of this study reveal that the increasing prices of metal-mineral commodities (referred to as "greenflation") are largely driven by global factors within the commodity demand chain. These factors include the growing consumption of renewable energy, the rising importation of commodities required for renewable energy production, and global inflation. Moreover, the study indicates that the behaviour of real exchange rates can be explained by economic fundamentals, specifically the real commodity market prices and the productivity differential of select countries. Notably, the empirical evidence presented in this essay underscores the significant role played by fluctuations in real commodity prices within the fossil and renewable energy market sub-sectors in explaining the long-term equilibrium movements of real exchange rates.

1.4.4 Essay 4: Shock and Spillover Effects of Global Commodity Markets on some African Equity Markets

The single-authored essay in Chapter 5 delves into the correlation between commodity market prices and financial markets in Africa. Its main objective is to examine how the financialisation of commodity markets affects the African equity market, specifically through shock and spillover mechanisms. Financialisation, a topic extensively discussed among financial economists, entails the increased involvement of financial and speculative investors without direct interest in the underlying commodities. These investors see commodities as alternative asset classes in their investment portfolios, utilising them for hedging or diversification purposes. Erb and Harvey (2006) propose that speculative activity in commodity markets has a historical presence, suggesting that it is not a new phenomenon. However, they observe that prior to the global economic and financial crises of 2008–2009, financial investors had limited involvement in these markets. Conversely, Gorton and Rouwenhorst (2006) argue that post-crises, institutional investors and hedge funds significantly increased their participation in commodity markets, signalling a notable shift in market dynamics after the global crises.

This phenomenon gained considerable attention around the year 2000 and likely contributed to the growing interest among investors in commodity markets. Previous studies have focused on examining the impact of the financialisation of commodity markets on equities, both in advanced and emerging countries (Main et al., 2018; Noor and Dutta, 2017; Arouri et al., 2012; Mensi et al., 2013). Additionally, Dimpfl et al. (2017) suggest that the measurement of this impact is heavily influenced by data and methodology. A study conducted by Haase et al. (2016) proposes that the financialisation of commodity markets can be measured in the equity market through various indicators such as returns, volatility, risk premia, and spillovers in both spot and futures markets. Several other studies have explored the relationship between financialisation, equity returns, and volatility. For example, Henderson et al. (2015), Cheng and Xiong (2014), Noor and Dutta (2017), and Lin et al. (2014) have all tested the impact of financialisation on equity returns and volatility. Arouri et al. (2011) investigated the influence of financialisation on equity returns by analysing volatility spillover effects from commodity to equity markets in different countries. The findings from these studies generally indicate a unilateral effect of commodity prices on the first and second moments of equity returns in certain countries. However, Haase et al. (2016) and Mensi et al. (2013) and (2017) have identified bi-directional volatility spillovers between equity and commodity markets.

In this dissertation, I aim to build upon previous studies by assessing the shocks and spillover effects of global commodity markets on select African equity markets. It is crucial to focus on African markets because the current discussion on the financialisation of commodity markets often overlooks their context. In summarising the findings, this research indicates that African equity markets are indeed influenced by risks that arise from the global commodity market. This suggests that the impact of financialisation on commodity markets is significant for African equity markets as well. Therefore, it is essential to understand that analysing the African equity market in isolation is not sufficient, as it is interconnected with the global financial markets. The dynamic interdependencies between these markets are time-varying and tend to increase when market risks are elevated. These results have important implications for speculative arbitrageurs, market hedgers, and international investors. For instance, they should consider the periods of negative time-varying correlations, which are essential for hedging against market risks.

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2 ASSESSING THE COMMODITY MARKET PRICE AND TERMS OF TRADE EXPOSURES OF MACROECONOMY IN EMERGING AND DEVELOPING COUNTRIES

Abstract.
This paper provides novel evidence on commodity market exposure, specifically examining the impacts of commodity price and terms of trade fluctuations on macro performance amongst 46 emerging and developing countries (EMDCs) in Africa, Asia, and the Latin American and Caribbean (LAC) region. We estimate the exposure of six macroeconomic variables to commodity prices and terms of trade. Our results reveal a strong and statistically significant long-run relationship between the vector of analysed world trade prices and macro variables in all EMDCs. However, based on the short-term reactions, only approximately 10% of the macroeconomic variation amongst the EMDCs is due to commodity market-related exposures. Furthermore, our results indicate that commodity market exposure is not uniform across countries, regions, and particularly between measures of exposure.

Keywords: commodity prices, terms of trade, structural vector autoregression, emerging and developing countries
JEL Codes: E30, E32, F41, O11, O14

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Assessing the Commodity Market Price and Terms of Trade Exposures of Macroeconomy in Emerging and Developing Countries

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ABSTRACT

This paper provides novel evidence on commodity market exposure, i.e., the impacts of commodity price and terms of trade fluctuations on macro performance amongst 46 emerging and developing countries (EMDCs) in Africa, Asia and the Latin American and Caribbean (LAC) region. We estimate the exposure of six macroeconomic variables to the commodity prices and terms of trade. Our results indicate that in overall terms, there is a strong and statistically significant long-run relationship between the vector of analyzed world trade prices and macro variables in all EMDCs. However, based on the short-term reactions, only about 10% of the macroeconomic variation amongst the EMDCs is due to commodity market-related exposures. Our results also indicate that the commodity market exposure is not unanimous across countries, amongst regions, or especially between measures of exposure.

KEYWORDS

Commodity prices; terms of trade; structural vector autoregression; emerging and developing countries

JEL

E30; E32; F41; O11; O14

1. Introduction

Primary commodities are of special importance for most emerging and developing countries (EMDCs). In some of these countries, commodities are imported inputs, whereas the other EMDCs are suppliers of those commodities. Both types of EMDCs are exposed to the commodity market price changes. For exporters, an increase in commodity prices channels an improvement in export revenues, hence, boosting the economy. In contrast, for the commodity importers, an increase in commodity prices has negative effects on economic performance. Standard open economy macro theory proposes that exogenous commodity price shocks have large impacts on commodity exporters and importers at macroeconomic level (see Fernández, Schmitt-Grohé, and Uribe 2017; Kose 2002; Schmitt-Grohé and Uribe 2018). However, the previous empirical studies are unable to provide a unanimous inference about the size of the impacts on different countries or on groups of countries, or on how to measure these shocks (based on commodity prices, or terms-of-trade values), what groups of commodities produce these shocks especially, or what econometric methods should be used in estimating the exposure. This is particularly an empirical question of high economic priority. Hence, there is an extensive demand for further results about the size and dynamics of commodity market exposure in different countries, especially among the ones that are most exposed to these shocks.

Previous inference about the significance of the commodity and standard terms of trade exposures is very heterogenous. Theoretical real business cycle models, which calibrate the impacts of standard and/or commodity terms of trade shocks on the macro variables propose that the commodity terms of trade shocks are the major source of economic fluctuations among the emerging and developing

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countries (see Aguiar and Gopinath 2007; Bidarkota and Crucini 2000; Broda 2004; Drechsel and Tenreyro 2018; Fernández, Schmitt-Grohé, and Uribe 2017; Fornero, Kirchner, and Yany 2016; Kose 2002; Mendoza 1997; Roch 2019; Schmitt-Grohé and Uribe 2018; Shousha 2016). In general, the results seem to be method dependent: For example, Schmitt-Grohé and Uribe (2018) have indicated that although the results may vary across countries, the terms of trade shocks would constitute only 10% of the macroeconomic fluctuations in the developing economics. This result is further supported by Fernández, Schmitt-Grohé, and Uribe (2017). On the other hand, Ben-Zeev, Pappa, and Vicondoa (2017) propose that the commodity terms of trade shocks could constitute almost half of the output fluctuations in Latin American economies. Sizable impact has also been reported in Roch (2019) estimates using heterogenous panel model show that the commodity price shocks can explain even 30% of the movements in output among the Latin American countries.

Furthermore, regarding the rivalry between the two main important international trade variables supposed to have macroeconomic effects in emerging and developing markets, i.e,, the standard terms of trade (*tot*) and the commodity terms of trade (*ctot*), there is a long list of studies that have previously focused on the role of especially the terms of trade effects on macro fluctuations (Agenor and Aizenman 2004; Raddatz 2007), starting from Harberger (1950) and Laursen and Metzler (1950). In their seminal studies, they showed that a negative shock to the terms-of-trade would worsen the current account. Later, Ostry and Reinhart (1992) found that the terms of trade shocks have a strong effect on real exchange rates and the current account. Another early study, which relates to ours is, e.g. Bidarkota and Crucini (2000), who combined national terms of trade data for developing countries with world prices of internationally traded primary commodities and found that the variation in the world prices of three or fewer key exported commodities may even account for 50% or more of the annual variation in the terms of trade of a typical developing country. They concluded that the commodity price fluctuations should be central features of studies of business cycle transmission across developing and industrialized nations.

In support, our evidence suggests that the EMDCs cannot be regarded as a homogenous group of countries with respect to the commodity market exposures. There are strong numerical differences in the exposures amongst countries, regions and commodity groups, but they all share the common feature that the commodity prices have a significant impact on the macroeconomic variables. The inference on the commodity price exposure seems to be depended on the variable used as a measure for commodity exposure. E.g. Harberger (1950) and Laursen and Metzler (1950), Ostry and Reinhart (1992) Bidarkota and Crucini (2000), Roch (2019), Lopez-Martin, Leal, and Fritscher (2017) all indicate that the inference on commodity price exposure depends on whether the standard terms of trade (*tot*) or the commodity terms of trade (*ctot*) is being used as an exposure variable. This disparity calls for further research. In order to make a firm conclusion about the phenomenon, we examined the exposure of 46 commodity dependent EMDCs to the world trade price changes, especially focusing on the effects of *ctot, tot*, and global commodity price indices (*gcp)*. We use the Gruss and Kebhaj (2019) commodity price data, which plays an integral part in our study. This new dataset is completely different e.g. compared to Bidarkota and Crucini (2000) since it focuses both on imports and exports prices and quantities.[1]

Our main contributions regarding the role of commodity market exposure are the following. First, individual macroeconomic variables in EMDC are somewhat differently exposed to the *tot, ctot*, and *gcp* shocks. However, there seems to be a common long-run, stationary relationship between all the individual cyclical macro variable series and the three price measures in our data set. This relationship has a statistically significant error-correction parameter in almost all country groupings and for all the macroeconomic variables of interest in our analysis. This is a new, strong finding in the EMDC data. It emphasizes the strong price effects of global markets, and hence, output, consumption, investment, trade balance, inflation and exchange rate exposure to commodity and price shocks. Second, based on the short-run shock effect analyses the standard terms of trade exposure also transmits the non-commodity market price effects, which are essentially influenced by the non-commodity exports and imports compositions (e.g. services). Third, many developing countries have specialized in only one or a few commodities in their exports or imports. In effect, based on our results the individual commodity price indices, e.g. for minerals, energy or agricultural products' prices for all the countries, may not adequately capture the country-specific shocks.[2] Moreover, the global commodity markets are strongly correlated in terms of the market prices (see Byrne, Fazio, and Fiess 2013). Therefore, the use of a global (aggregate) commodity market index series as one alternative price series in our analyses captures this phenomenon.

We also shed new light on the idea that some of the macroeconomic variables in EMDCs may possibly be more exposed to the world trade market prices than others. This follows the assumption of the small open economy real business cycle (RBC) theory, which suggests that different sectors/variables of the macroeconomy (aggregate output, private consumption, private investments, international trade, general price level and real effective exchange rate) respond differently to different exogenous price shocks across countries. Hence, using multiple world trade price series in this study also controls for the heterogeneity in individual/group exposures in this respect. For example, we use the country-specific commodity terms of trade index to account for the differences in the country's commodity market trade (imports and exports) weighted by the country's output. We expect that this variable better captures the effects of commodity price fluctuations on different group/country performance, compared with the standard terms of the trade index. Finally, in all our analyses we acknowledge the concerns raised by Hamilton (2018) about the use of Hodrick and Prescott 1997 filtering in macro econometric modeling. Therefore, we end up using the Hamilton (2018) filtering for the cyclical components in our analysis. This is also a novel application among the studies of commodity exposure which typically employs HP filtering if needed.[3]

Our findings can be summarized as follows. First, the results show that the newly constructed commodity terms of trade dataset from the International Monetary Fund (IMF), described in Gruss and Kebhaj (2019), has a strong potential to be used when analyzing the aggregate macroeconomic fluctuations among the EMDCs. The estimates from the Pooled Mean Group (PMG) estimator of Pesaran, Shin, and Smith (1997, 1999) propose a remarkably strong symmetry in terms of long run adjustment of macro variables, ca. −0.50, (output, consumption, investment trade balance, consumer price index and exchange rate) toward the long-run equilibrium after a common commodity price shock (standard terms of trade, commodity terms of trade and global commodity price index) across the group of countries analyzed. The PMG estimates verified further the significant role of the global commodity price index especially when the long run effects are concerned. It had significant effect in 58% of cases across the macro variables among our 6 groups of countries. The significance of the short run exposures of macro variables were more alike. The number of significant impacts varied between 8 (for the commodity terms of trade and global commodity price index) and 5 (for the commodity terms of trade). PMG estimates also pointed out that the consumer prices are especially significantly exposed to the global commodity price index.

In addition, the short-run shocks (impulse responses) reveal that many of the real economic sectors in the Other (Latin American and Caribbean [LAC] and Asia) group of economies are more exposed to price changes compared to for example the African economies. This part of our results lends support to other related studies (e.g. Céspedes and Velasco 2012; Collier and Goderis 2012; Deaton and Miller 1996). Also, the non-commodity exporting economies are severely exposed to the world trade price movements compared to the reactions amongst the commodity-dependent economies. Overall, the findings on average, suggest that these shocks account for less than 10% of the variation in the macroeconomic variables. This corroborates with e.g. Schmitt-Grohé and Uribe (2018) findings. In particular, the impulse responses reveal how real aggregate output and private investments improve because of favorable price changes, which strongly supports the evidence in Roch (2019). Most importantly, we find that a favorable commodity price shock appreciates the real exchange rate, which makes these economies competitively cheaper in terms of foreign goods, but the downside effect is a rise in the prices of consumer goods (inflationary effects) and a prominent contraction in private consumption. Our findings concerning the standard terms of trade also confirm the results of Schmitt-Grohé and Uribe (2018), who used similar terms of trade series in the empirical analysis.

The rest of the paper is structured as follows. Section 2 presents our empirical approach. Section 3 describes the data. The empirical results and discussions are presented in Section 4. Section 5 concludes with policy recommendations. The online appendix presents the theoretical RBC model motivating our empirical analyses. The appendix displays also the additional empirical results.

2. Econometric Model

The theoretical motivation of our empirical approach is based on a small, open economy RBC macro model described in Online Appendix A, which follows the previous analyses such as those of Mendoza (1995, 1991), Schmitt-Grohé and Uribe (2018) and Wickens (2008). The empirical form of the model is analyzed using the Structural Vector Autoregression (SVAR) approach, as previously utilized, for example, in Fernández, Schmitt-Grohé, and Uribe (2017), Schmitt-Grohé and Uribe (2018), and Shousha (2016). The SVAR modeling starts with a reduced form VAR that takes the form:

$$z_{it} = \sum_{j=1}^{p} A_i x_{it-j} + e_{it}, e_{it} \sim N(0, \Sigma), \tag{1}$$

where z_{it} is a vector of dependent variables, A_i is $n\ x\ n$ matrix of the parameters on lagged variables, x_{it-j}denotes a vector of the lagged dependent variables, and e_{it} is a set of errors that have zero expected values and a variance-covariance matrix Σ. Hannan-Quinn (HQIC) information criterion choose $p = 2$ to be the number of optimal lags. The order of variables in the VAR model is given as:

$$z_{it} = [a_{it}, b_{it}]' \, and \, x_{it-j} = [a_{it-j}, b_{it-j}]' \tag{2}$$

where $a_{it} = (ctot_{it}, tot_{it}, gcp_{it})\prime$ denotes the exogenous price variable vector, and $b_{it} = (y_{it,} c_{it}, inv_{it}, tb_{it} cpi_{it}, er_{it})\prime$ denotes the endogenous macro variables in our analysis. Based on the small, open economy structure of our theoretical model described in Appendix A, we identified the commodity terms of trade (*ctot*), the standard terms of trade (*tot*) and the global commodity price (*gcp*) as the alternative exogenous price variables affecting macroeconomic variables: the aggregate output (*y*), consumption (*c*), investments (*inv*), trade balance (*tb*), consumer price index (*cpi*) and real effective exchange rate (*er*) fluctuations. Therefore, to scrutinize the impacts of the exogenous price shocks on the macro variables, we formulate a SVAR model that takes the form:

$$A_0 z_{it} = \sum_{j=1}^{p} A_{ij} x_{it-j} + \varepsilon_{it}, \varepsilon_{it} \sim N(0, \Sigma). \tag{3}$$

Because the errors (e_{it}) in the reduced form VAR (Equation (1)) are correlated, we had to formulate Equation (3) so that the error term $\varepsilon_{it} = B^{-1/2} e_{it}$ becomes a linear combination of the structural shocks$B$.Here, A_0 and A_i are $n\ x\ n$ matrices of parameters, andΣ is a diagonal matrix of variances and covariances indicating that the errors are now independent of each other. For the identification of exogenous structural shock effects, we ordered the variables in the A_0 matrix based on a Cholesky decomposition (lower triangular matrix), similar to Fernández, Schmitt-Grohé, and Uribe (2017) and Shousha (2016). This is to ensure that the vector of endogenous (macro) variables does not have any contemporaneous impact on the vector of exogenous world trade prices by the assumption of small, open economy model described in Appendix A. The ordering of variables in $A_0$is important because it enables us to uniquely identify the shocks from the exogenous prices, *ceteris paribus*. Hence, if we assume A_0 is a non-singular $n \ x \ n$ matrix, that is invertible, then we can rewrite Equation (4) in a reduced form as:

$$z_{it} = \sum_{j=1}^{p} A_{ij}^{*} x_{it-j} + \varepsilon_{it}^{*}, \varepsilon_{it}^{*} \sim N(0, \Sigma^{*}), \\ \text{where } A_i^{*} = A_0^{-1} A_i \text{ and } \varepsilon_{it}^{*} = A_0^{-1} B^{-1/2} e_{it}, \tag{4}$$

where ε^{*} represents the mutually uncorrelated reduced form innovations. This form normalizes the covariance matrix $E(\varepsilon_{it}\varepsilon_{it}{}') = \Sigma$ of the structural errors, so that the reduced-form error covariance matrix is $E(\varepsilon_{it}^{*}\varepsilon_{it}^{*}) = \Sigma^{*} = A_0^{-1}E(\varepsilon_{it}\varepsilon_{it}{}')A_0^{-1}$. Now, the elements in A_0 are the short-run contemporaneous parameter values for the variables.A_i captures the dynamics in the system, and A_0^{-1} becomes a structural multiplier that serves as the weights. Following the approaches of Drechsel and Tenreyro (2018) and Schmitt-Grohé and Uribe (2018), we choose A_0^{-1} so that the structural shocks are given by one standard deviation (*SD*), which can be interpreted as a group unit shock. This enables us to simulate the impulse response functions (IRFs) and forecast error variance decomposition (FEVD) from the structural model with our interest in the exogenous prices giving the impulses and endogenous variables as responding to them.

In addition to utilizing the structural VAR approach, that is based on the assumption of stationarity of the analyzed vector of time series variables in a panel form, we also analyze specifically whether our main macroeconomic variables have a long-run steady state relationship with the world trade prices i.e., *ctot, tot*, and the *gcp* using a Vector Error Correction Model (VECM) representation of autoregressive distributed lag (ARDL) model.[4] However, considering the dimensions of our panel data, both the cross-sectional (N = 46 EMDC's) and time-series (T = 37 years) dimensions are fairly large. Hence, we use the Blackburne and Frank (2007) approach, to account for the fact that the asymptotics of large N and large T dynamic panels (with prominent non-stationarity) are different from the asymptotics of traditional large N and small T dynamic panels. We estimate the VECM representation of our panel data separately for each macroeconomic (y) variable and the vector of price (x) variables in the form[5]

$$\Delta y_{it} = \phi_i \left(y_{i,t-1} - \theta_i' x_{it} \right) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}'^{*} \Delta x_{i,t-j} + \mu_i + \in_{it}, \tag{5}$$

where $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij}), \theta_i = \sum_{j=0}^{q} \delta_{ij}/(1 - \sum_k \lambda_{ik}), \quad \lambda_{ij}^{*} = - \sum_{m=j+1}^{p} \lambda_{im}, \quad j = 1, 2, \ldots, p-1,$ and $\delta_{ij}^{*} = - \sum_{m=j+2}^{q} \delta_{im}, j = 1, 2, \ldots, q-1$

The parameter ϕ_i is the error-correcting speed of adjustment term, and if it is zero, then there would be no evidence for a long-run relationship. This parameter is expected to be significantly negative under the prior assumption that the (levels) relationships between the variables of our interest show a return path to a long-run equilibrium. Of particular importance is the vector θ_i', which contains the long-run relationships between the variables. We estimated the model using the Pooled Mean Group estimator introduced by Pesaran, Shin, and Smith (1997, 1999). It allows both the heterogeneous short-run dynamics and common long-run elasticities. Our specification includes the (cyclical components of) macro variable of interest and the set of price variables (*ctot, tot*, and *gcp*) in each case. Often only the long-run parameters are of primary interest, and the results of the *pmg* option in Stata include the long-run parameter estimates and the averaged short-run parameter estimates.

3. Data

We collected annual observations on the country-specific commodity terms of trade, the standard terms of trade and six country-specific macroeconomic variables covering the period from 1980 to 2017 for 46 EMDCs. In addition, we used the global commodity price index data covering the period from 1980 to 2016. The sources of the data were the World Bank, IMF, UNCTADStat, and the paper by Gruss and Kebhaj (2019). We categorized our variables into two main blocs as follows: (a) The exogenous price bloc: the commodity terms of trade (*ctot*), the standard terms of trade (*tot*) and the global commodity price (*gcp)*; and (b) The endogenous (macroeconomic) variable bloc: aggregate output (*y*), private consumption (*con*), private investments (*inv*), trade balance (*tb*), consumer price index (*cpi*) and real effective exchange rate (*er*).

For the construction of our set of exogenous world trade price series, we used various measures to identify the exposure. First, we used the World Development Indicators (WDIs) trade-weighted export to import unit value index as the measure of the standard terms of trade (see Schmitt-Grohé and Uribe 2018). Second, we used the newly introduced GDP-weighted commodity export to import price series as the measure of commodity terms of trade (see Gruss and Kebhaj 2019) and the commodity market price (all group) index from the World Bank pink sheet (2019).[6] Based on the theoretical model given in the online Appendix A, our set of endogenous variables consisted of similar variables to that of Schmitt-Grohé and Uribe (2018), and we retrieved it from the World Bank WDI database.[7] Eligibility criteria for choosing a specific EMDC to be included in our panel of countries required that an individual country had to satisfy the following criteria: 1; The country must be considered a commodity export dependent country in one of the three commodity export sectors (agricultural products, minerals or energy commodities) by UNCTAD,[8] 2; It must be considered as an emerging or developing country/market by IMF, UNCTAD or Morgan Stanley Capital International (MSCI) classification, and 3; It must have at least 30 years of consecutive annual on all the variables available in WDI or IMF databases.

Ultimately, 46 countries satisfied the screening criteria to be included in this study. Thereafter, we categorized the countries first into three regions: 22 African countries, 10 Asian countries and 14 LAC countries. The second grouping was based on the commodity sector dependence by UNCTAD (2019); it consisted of 15 agriculture export dependent countries, 9 minerals dependent, 7 energy dependent and 15 non-commodity export dependent countries and their exchange rate regimes (see Table B.1).[9] Considering that our theoretical model was set up to examine fluctuations (cycles) in macroeconomic variables, we had to transform our data series by taking log values and detrending them using the Hamilton (2018) filter to obtain the cyclical components of the data.

After the transformation, we performed panel unit root tests on the raw data and the cyclical component using the Levin, Lin, and Chu (2002) test for a common unit root in the panel, and the Im, Pesaran, and Shin (2003) test for individual unit roots in the panel. The panel unit root test results (cf. Table D.1) show that some of the variables in the raw data, i.e. the commodity terms of trade, global commodity prices, and output and consumer price indexes, are I(1), whilst the other variables are I(0). As expected, the cyclical component of the Hamilton filtered data for all the variables was stationary, i.e. I(0) at levels. Fig. B.1 plots the cyclical data of the macroeconomic variables and the world trade prices for some selected economies. See also Tables B.2. and B.3 for the key descriptive statistics on the analyzed macroeconomic variables for the groupings.

4. Empirical Results and Discussion

4.1. Long-run and Short-run Dynamic Relationships

This section presents and discusses the main empirical results in the following order. Because our panel unit root tests indicated that the cyclical components of e.g. the macro variables seem to be stationary processes, the natural starting point would be directly the SVAR-based analysis. However, considering the high first order autocorrelation coefficients for some of the variables analyzed (cf. Tables B.2 and B.3), we have reasons to believe that focusing only on the SVAR-based results might yield biased results in some cases. Because of this, and the obvious possibility that due to having both large cross-sectional (N) and large time-series (T) dimensions in our data, the assumption of stationarity and homogeneity of slope parameters might be inappropriate, we start our reporting and discussion of results from the VECM representation given in Equation (5) above. Tables 1 and 2 report the long-run cointegration relationship (denoted LR) which is normalized for the macro-variable in question, and the vector of world trade prices, i.e, *ctot, tot*, and *gcp*, and also the short-run dynamics (denoted SR)

As we see from the results in Table 1, the ARDL-based panel cointegration procedure allowing for heterogenous effects amongst the cross-sectional units reveals that there indeed are some interesting long-run relationships between the variables. The most striking result is that in all the cases, the error correction term (ECT) is statistically significant even at 1% risk level and it also has an economically appealing interpretation. The size of the economically relevant negative error correction coefficient varies from −0.11 (for aggregate output in the group of 24 'Other Countries' to −0.67 for the aggregate output in the 'Energy'-dependent countries. This finding is really striking, since it reveals the extreme importance of the equilibrium relationships between the local macro variables and global commodity prices, and the country-specific commodity-terms of trade (*ctot*) and standard terms of trade (*tot*) series. The implication is that the commodity market behavior really has a strong role in determining the macroeconomic equilibrium conditions in the countries analyzed.

Furthermore, the long-run relationship (LR) between each individual macro variable and the three price variables seems to vary a lot between the various country groupings, and it varies much more than the role of the ECT-term. For example, exchange rate and investments are the variables that react often and statistically most significantly to the *ctot, tot* and *gcp* changes. In addition, aggregate consumption in the energy, and agricultural production dependent countries reacts negatively in the long-run relationship to the rising *ctot* values. Moreover, the reaction is clearly stronger in both these (individual coefficients in the LR-relationship are −0.51 and −0.49, respectively) compared to the non-commodity dependent countries (with coefficient −0.33). On the other hand, the exchange rate reactions are very strong in the LR-relationship for both the agricultural dependent countries and African countries (of which many are actually dependent on agricultural production), and in these cases all the *ctot, tot*, and *gcp* series have a statistically significant parameter estimate in the long-run equilibrium relationship. Similar conclusions cannot be drawn so strongly for any of the other groupings or macro variables.

In overall terms, the results reported in Table 1 suggest that the degree of variation in both the long-run (LR) and short-run (SR) dependencies amongst the three price variables and the individual macro indicators is very strong. However, the utilized VECM-representation of our data set revealed also very strongly, that the analyzed price variables (*ctot, tot*, and global commodity price index) are indeed extremely important for all the macro variables and for all the groupings of our country-level data. The mean value of the ECT-term coefficient is −0.525, and the standard deviation is 0.015, so it seems that in these data, in average terms about half of the error in the long-run relationships between the price variables and the macro situation (irrespective of the macro indicator used) is corrected every year, and this is indeed a strong error-correction mechanism also in economic meaning. However, because the short-term results are much more heterogenous already based on this first stage of our empirical analyses, the next step of our analysis is based on focusing on the relationships between the variables in SVAR representations of our data.

4.2. Shock Reactions

This section presents the impulse responses (IRFs) and forecast error variance decomposition (FEVD) results obtained from the SVAR representations given in Equations (1)–(4) above. Figures 1 and 2 present the IRFs obtained from one standard deviation shock to the world trade prices in rows (a)–(c)

Table 1. ARDL-VECM estimates for output, private consumption and investment.

		Output			Consumption			Investment		
Panel 1		*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*
Commodity dependent										
Agricultural products' (15)	LR	**0.03 (0.01)****	-0.00 (0.00)	0.00 (0.00)	**-0.49 (0.13)*****	**0.03 (0.01)***	-0.00 (0.01)	**-0.20 (0.11*)**	**-0.02 (0.01)****	0.02 (0.01)
	SR	5.73 (6.50)	-0.50 (0.54)	1.02 (1.06	0.01 (0.16)	0.02 (0.03)	-0.00 (0.01)	0.03 (0.07)	-0.01 (0.01)	-0.00 (0.01)
	ECT	**-0.51 (0.03)*****			**-0.53 (0.04)*****			**-0.51 (0.03)*****		
Energy (7)	LR	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	**-0.51 (0.13)*****	**0.04 (0.02)****	-0.02 (0.02)	**0.26 (0.15)***	-0.04 (0.03)	0.03 (0.02)
	SR	24.24 (23.29)	-1.86 (1.49)	1.14 (0.87)	-0.03 (0.23)	**0.06 (0.03)****	-0.00 (0.01)	-0.11 (0.12)	-0.00 (0.02)	-0.01 (0.00)
	ECT	**-0.67 (0.05)*****			**-0.52 (0.02)*****			**-0.49 (0.04)*****		
Mineral (9)	LR	0.01 (0.02)	0.00 (0.00)	**0.01 (0.00)*****	-0.03 (0.02)	-0.01 (0.02)	-0.20 (0.17)	**0.04 (0.01)****	**0.04 (0.02)****	
	SR	2.70 (4.37)	-0.51 (0.60)	0.14 (0.22)	0.11 (0.48)	0.03 (0.04)	-0.00 (0.02)	0.22 (0.15)	-0.07 (0.03)***	-0.01 (0.01)
	ECT	**-0.52 (0.03)*****			**-0.61 (0.05)******			**-0.51 (0.04)*****		
Non-commodity dependent (15)	LR	-0.04 (0.05)	**0.02 (0.01)****	**0.01 (0.00)****	**-0.33 (0.10)*****	**-0.04 (0.02)*****	-0.00 (.0.01)	**-0.20 (0.10)****	**0.05 (0.02)*****	**0.03 (0.00)*****
	SR	-25.16 (23.83)	3.92 (3.67)	1.08 (0.98)	-0.03 (0.12)	0.01 (0.02)	0.00 (0.00)	-0.01 (0.11)	**-0.05 (0.01)*****	0.00 (0.01)
	ECT	**-0.48 (0.04)*****			**-0.58 (0.04)*****			**-0.49 (0.04)*****		
Panel 2										
Africa (22)	LR	0.01 (0.01)	0.00 (0.00)	**0.03 (0.01)*****	**-0.40 (0.09)*****	**0.03 (0.01)****	-0.01 (0.01)	-0.03 (0.09)	-0.01 (0.01)	**0.04 (0.01)*****
	SR	-0.07 (0.57)	-0.07 (0.12)	0.06 (0.17)	0.04 (0.21)	0.01 (0.03)	-0.00 (0.01)	0.06 (0.09)	**-0.04 (0.01)****	-0.01 (0.01)
	ECT	**-0.50 (0.04)*****			**-0.56 (0.03)*****			**-0.51 (0.02)*****		
Other countries (24)	LR	10.11 (7.00)	0.13 (0.92)	**2.93 (1.12)*****	**-0.29 (0.07)*****	**-0.03 (0.01)****	-0.00 (0.01)	-0.07 (0.07)	0.01 (0.01)	**0.02 (0.00)*****
	SR	-4.09 (17.2)	1.41 (2.40)	**1.45 (0.85)***	-0.00 (0.09)	-0.00 (0.01)	-0.01 (0.01)	-0.05 (0.06)	**-0.02 (0.01)***	-0.00 (0.01)
	ECT	**-0.11 (0.05)*****			**-0.57 (0.03)*****			**-0.50 (0.02)*****		

This table reports the long-run (LR), and short-run (SR) relationships, i.e., the parameter estimates for the world trade prices (*ctot, tot*, and *gcp)* in the cointegration vector normalized always with respect to the macro variable (output, consumption, and investment) in question (LR-part) and for their short-term, difference effects (SR-part). The model is given as $\Delta y_{it} = \phi_i\left(y_{i,t-1} - \theta_i' X_{it}\right) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \delta_{ij}'^{*} \Delta X_{i,t-j} + \mu_{it} + \in_{it}$, where y_i is the dependent (macro variable), and X_i is a vector of world trade prices. We estimated the model using the *xtpmg* command in Stata, that is based on the Pesaran, Shin, and Smith (1997, 1999) PMG estimator, and described in Blackburne and Frank (2007). The standard errors of parameter estimates are given in parentheses, and *, **, *** denote the 10%, 5% and 1% statistical significance levels, respectively. Here, ECT (ϕ_i, $-$coefficient) denotes the error correction term (expected to be negative and statistically significant if the relationship between the variables exhibits return to long run equilibrium. *ctot* refers to the commodity terms of trade index, *tot* the standard terms of trade index, and *gcp* the global commodity price index. All the results are based on filtering the cyclical component from the original data series based on the Hamilton (2018) filtering procedure.

Table 2. ARDL-VECM estimates for trade balance, consumer price index and real exchange rate.

		Trade balance			Consumer price index			Exchange rate		
Panel 1		*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*
Commodity dependent										
Agricultural products' (15)	LR	0.16 (0.14)	-0.02 (0.02)	-0.01 (0.01)	0.04 (0.11)	-0.01 (0.02)	**0.07 (0.01)*****	**-1.98 (0.56)*****	**0.47 (0.08)*****	**0.18 (0.05)*****
	SR	-0.01 (0.07)	0.02 (0.02)	-0.00 (0.01)	0.08 (0.26)	0.03 (0.02)	**-0.04 (0.01)*****	**1.28 (0.52)****	**-0.23 (0.07)*****	-0.06 (0.06)
	ECT	**-0.60 (0.03)*****				**-0.53 (0.04)*****			**-0.50 (0.07)*****	
Energy (7)	LR	**-0.51 (0.29)***	-0.00 (0.03)	0.02 (0.02)	0.02 (0.16)	**-0.07 (0.03)****	**0.12 (0.03)*****	0.12 (0.74)	-0.02 (0.12)	**0.24 (0.09)*****
	SR	0.08 (0.16)	0.04 (0.03	**-0.04 (0.02)****	1.28 (1.40)	-0.12 (0.14)	**-0.05 (0.01)*****	0.44 (0.88)	0.24 (0.33)	-0.17 (0.29)
	ECT		**-0.55 (0.05)*****			**-0.59 (0.06)*****			**-0.53 (0.07)*****	
Mineral (9)	LR	-0.07 (0.25)	-0.05 (0.03)	0.01 (0.02)	-0.01 (0.22)	-0.04 (0.03)	**0.12 (0.03)*****	**-0.68 (0.38)***	0.02 (0.06)	**0.19 (0.06)*****
	SR	-0.30 (0.29)	**0.06 (0.03)****	-0.01 (0.01)	**-0.70 (0.40)***	**0.04 (0.02)****	**-0.06 (0.02)*****	-1.81 (3.35)	0.78 (0.83)	0.15 (0.23)
	ECT		**-0.57 (0.06)*****			**-0.48 (0.04)*****			**-0.61 (0.08)*****	
Non-commodity dependent (15)	LR	-0.07 (0.13)	0.00 (0.01)	**-0.03 (0.01)*****	**-0.53 (0.13)*****	0.03 (0.03)	**0.06 (0.01)*****	0.41 (0.38)	**0.12 (0.06)****	**0.20 (0.03)*****
	SR	0.06 (0.09)	-0.01 (0.01)	-0.00 (0.01)	-0.16 (0.25)	-0.03 (0.02)	**-0.04 (0.02)****	0.40 (0.47)	0.07 (0.07)	0.01 (0.03)
	ECT		**-0.58 (0.04)*****			**-0.56 (0.04)*****			**-0.57 (0.04)*****	
Panel 2										
Africa (22)	LR	-0.06 (0.13)	-0.01 (0.02)	-0.00 (0.01)	-0.06 (0.11)	**-0.05 (0.02)****	**0.13 (0.02)*****	**-1.02 (0.33)*****	**0.22 (0.05)*****	**0.08 (0.04)***
	SR	-0.07 (0.14)	**0.03 (0.02)****	-0.02 (0.01)	0.33 (0.50)	-0.01 (0.05)	**-0.07 (0.01)*****	-0.36 (1.37)	0.23 (0.34)	0.08 (0.11)
	ECT		**-0.60 (0.03)*****			**-0.53 (0.04)*****			**-0.57 (0.05)*****	
Other countries (24)	LR	-0.01 (0.11)	0.00 (0.01)	**-0.02 (0.00)*****	**-0.28 (0.08)*****	0.02 (0.02)	**0.06 (0.01)*****	0.12 (0.34)	0.01 (0.05)	**0.23 (0.03)*****
	SR	-0.01 (0.01)	0.00 (0.01)	0.00 (0.00)	-0.25 (0.18)	-0.01 (0.02)	**-0.02 (0.01)****	**0.90 (0.34)****	0.06 (0.10)	-0.08 (0.07)
	ECT		**-0.56 (0.02)*****			**-0.54 (0.03)*****			**-0.54 (0.03)*****	

This table reports the long-run (LR), and short-run (SR) relationships, i.e., the parameter estimates for the world trade prices (*ctot, tot*, and *gcp*) in the cointegration vector normalized always with respect to the macro variable (trade balance, inflation and real exchange rate) in question (LR-part) and for their short-term, difference effects (SR-part). See (cf. Table 1) for the notations.

for the African and Other economies groups.[10] We chose this specific setup to be reported and discussed in more details, because this enables us to compare our results directly with some previous studies, such as Ben-Zeev, Pappa, and Vicondoa (2017), Fernández, Gonzalez, and Rodriguez (2018), Schmitt-Grohé and Uribe (2018), Shousha (2016) and Mendoza (1995), who also found that the commodity terms of trade, standard terms of trade and global commodity price shocks have varying effects on different macroeconomic variables (aggregate output, private consumption, private investments, trade balance, consumer price index and real effective exchange rate) amongst the EMDCs. Row (b) in Figure 1 shows the macroeconomic variables' response to one standard deviation shock from the commodity terms of trade index. The reactions suggest that when a favorable commodity terms of trade shock hits the African economies, real economic activities such as the aggregate output will contract immediately, and private consumption as well, a year after the shock, whilst private investment improves 2 years after the shock. These impacts are statistically significant within a 95% confidence margin. In comparison with row (c), a similar characteristic can be seen that a favorable standard terms of trade shock causes aggregate output to expand for almost two years. This also causes the real effective exchange rate to appreciate within two years after the shock. The African economies' exposure to the global commodity price shocks suggests that the aggregate output and private investments expand a year after a favorable price shock. However, the region may experience depreciation in the real effective exchange rate immediately due to the shock (see row a).

Notably, the aggregate output reacts unfavorably to commodity terms of trade shock, which was unexpected. The reason for this is not obvious. A possible explanation for the reaction of the output is that the African economies export primary commodities and then import the value-added ones. Assuming a rise in commodity prices directly translates to a rise in the cost of imported products as inputs, this may adversely affect the output amongst the African economies. Figure 2 presents the reactions of the macroeconomic variables in the Other group of economies to one standard deviation shock in the world trade prices. Here, the significant reactions are much stronger compared to the

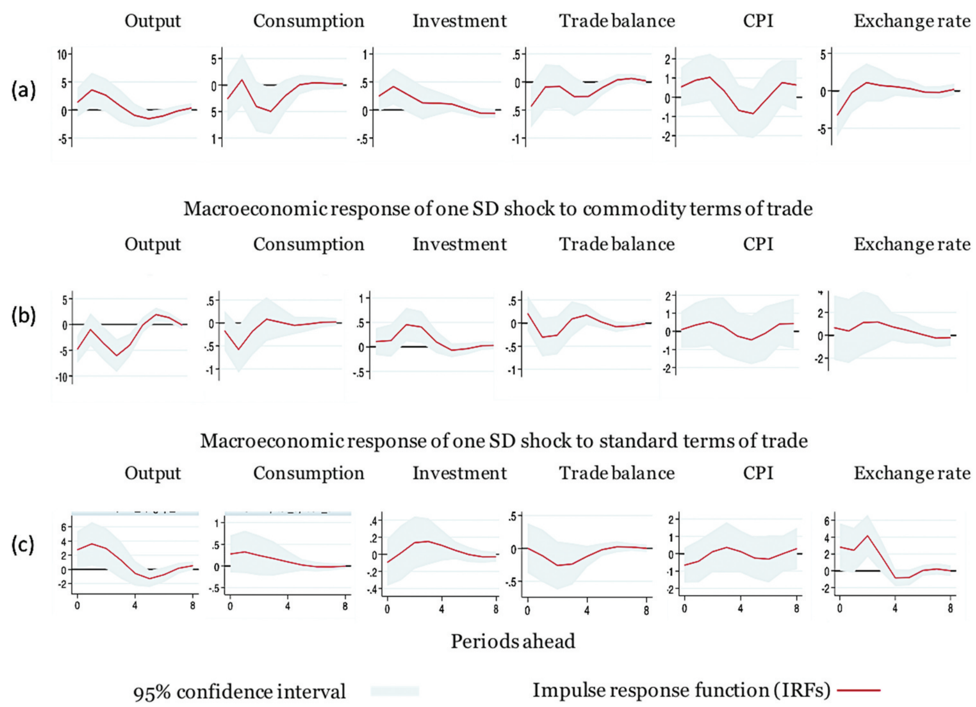

Figure 1. Impulse responses for the African economies. *Source*: Authors' calculation based on Equation (4) of the empirical model and Equations (A.18) – (A.33) of the theoretical model.

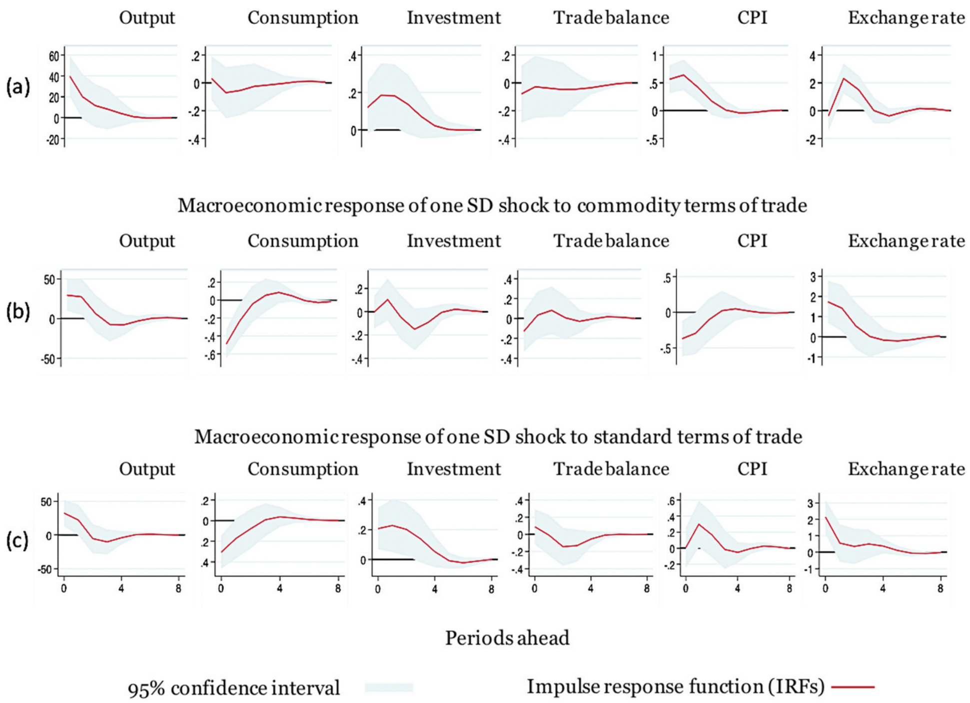

Figure 2. Impulse responses for the Other economies. *Source*: Authors' calculation based on Equation (4) of the empirical model and Eqs. (A.18) – (A.33) of the theoretical model.

African economies. It's obvious from Figure 2 row (a) that a favorable shock in the global commodity price index causes an expansion in the aggregate output, private investments and consumer price index immediately after the shock. Furthermore, the real effective exchange rate will appreciate one year after the shock. These reactions are statistically significant within the 95% confidence margins. Similarly, the responses shown in row (b) indicate that a favorable commodity terms of trade shock causes output to rise immediately, whilst the real effective exchange rate appreciates after a year (see also Roch 2019). However, private consumption and consumer price inflation seem to contract immediately after the shock. These findings are in line with those of Ben-Zeev, Pappa, and Vicondoa (2017).

Figure 2 row (c) shows that the standard terms of trade shock expands real economic activities such as aggregate output and private investments and appreciates the real exchange rate. Private consumption seems to be contracting immediately, which also confirms the findings of Schmitt-Grohé and Uribe (2018). Most importantly, we find that unlike for the data on African economies, the results presented in Figure 2 rows (a–c) suggest that within a 95% confidence margin, a favorable shock in the world trade prices causes aggregate output to expand, and the prices of foreign goods become cheaper as a result of the appreciation in the real exchange rate amongst the Other group of economies. Together, these results indicate that when a shock hits African or the group of Other economies, the effects on their macroeconomic performance persist for at least two to 4 years before they converge to zero. As an implication from this finding, we highlight the extent of exposure in these economies to the world trade price shocks and the chain of events on how these impacts favorably or adversely influence and persist in these economies. These results are in general consistent with that of e.g. Drechsel and Tenreyro (2018), Mendoza (1992, 1995), Kose (2002) and Schmitt-Grohé and Uribe (2018). Furthermore, a robustness check based on using alternatively computed cyclical observations for the analyzed variables from Hodrick and Prescott (1997, HP) filtering procedure reveals the consistency of our results, too.[11]

Figs. C.1 – C.4 report the responses of macroeconomic variables to a one standard deviation shock to the world trade price for the commodity dependent groups of economies. In general, results show both favorable and unfavorable reactions to the world trade price shocks for different commodity dependent groups. These reactions are statistically significant in many cases. We find this as further implications on how the EMDC's are ex-ante exposed to the world trade prices irrespective of their production structure. In addition, the strong and significant reactions of the macro variables in many cases confirms the long-run relationship between the macro variables and the commodity market behavior which, as was witnessed based on our ARDL-VECM analyses, indeed has a strong role in determining the macroeconomic equilibrium conditions in the analyzed countries.

The theoretical framework (see Online Appendix A) of this study assumes that the groups of economies analyzed are small open economies. They have minimal or no control over the global commodity import/export markets as well as in other goods market price movement. This makes their economies vulnerable to any unanticipated price movements in the world market. Our results have revealed some important dynamics in their economic activities responding to exogenous shocks. We also detect that some economies have benefited from the global commodity price booms in the form of improvement in aggregate output and investment. We also observe that appreciation in the real exchange rates is common, which makes those economies competitively cheaper in terms of foreign goods, but the downside of this is the subsequent rise in the price of consumer goods (inflationary effects) and the declining private consumption. Overall, many of these exposures are consistent with the other related studies cited earlier, e.g. see Schmitt-Grohé and Uribe (2018).

However, in order to understand more profoundly the importance of these shocks affecting the country groups, we examined how much of the fluctuation in the economic activities can be explained by the world trade price shocks using forecast-error variance decomposition (FEVD). For this purpose, we decomposed the variance in the macroeconomic variables for each shock and projected it five years ahead. Tables C.1 and C.2 display the FEVD in Africa with respect to Other group of economies. Overall, the results show that less than 10% of the variations in aggregate output, private consumption, private investment, trade balance, consumer price index and real effective exchange can be explained by the world trade prices. The results suggest that the commodity terms of trade and global commodity market price shocks may account for a greater proportion compared to the standard terms of trade index shocks.

5. Conclusions

This study assessed the macroeconomic exposures of different types of commodity market dependent Emerging and Developing Countries (EMDC) on the recent fluctuations in global commodity prices and the terms of trade. For this purpose, we first constructed a theoretical model that identifies the main exogenous shocks affecting some key macroeconomic variables in 46 emerging and developing, small open economy countries. Based on this theoretical framework, we then analyzed the long- and short-run relationships between three world trade price series and six key macroeconomic indicators.

Our main results can be summarized as follows. First of all, our Pooled Mean Group ARDL-VECM modeling approach of the long-run relationships between commodity terms of trade, standard terms of trade and global commodity market index series and the analyzed six macroeconomic variables reveals that there is a very strong long-run relationship amongst the EMDC data. This result is very consistent in all the country groupings, and it can be given as an error correction representation amongst the variables suggesting quite rapid adjustment of the macroeconomy to the deviations from the long-run equilibrium relationship due to shocks in commodity prices. Furthermore, from the short-run analyses we find that many of the real economic sectors in the Other (LAC and Asia) group of economies are more exposed to the world trade price changes compared to the group of African economies. For the economies grouped according to their production structure, the results reveal that the non-commodity export-dependent EMDC economies are even more sensitive to the world trade price fluctuations compared to the commodity-dependent sector economies, such as agricultural products and minerals.

Finally, our short-run, shock effect findings reveal that, on average, less than 10% of the variance in the key macroeconomic variable fluctuations can be explained by the world trade price shocks in all the groups. Nevertheless, our results show in general that all the commodity-dependent countries in Africa, Asia, Latin America, and the Caribbean are strongly exposed to the world commodity trade price fluctuations. Hence, this study suggests that the future policies and decision-making should carefully acknowledge the impact of these world trade price shocks, especially for Africa and Latin American regions, which are most exposed to these shocks. In addition, we propose that the policy makers especially in African countries should pay attention to mitigating the unfavorable commodity terms of trade shocks.

Notes

1. In Bidarkota and Crucini (2000), the quantity of exports of each commodity item was assumed to be constant because they did not have access to the time series on trade quantities at the fine level of detail of the commodity price data series. In contrast to that, we exploit a dataset which is constructed utilizing the country-level, detailed commodity terms of trade series, based on both the exports and imports quantities, as well as the individual, global commodity market price series.
2. Hence, we argue that using only the standard terms of trade series or the individual commodity price indices to examine the unanticipated effects of world trade prices on the aggregate economies may not provide the best possible information on the effects of world trade prices on the macroeconomic performance of these countries (see also Fernández, Schmitt-Grohé, and Uribe 2017).
3. We also tested the models with the HP filtered data. In general, the HP filtered data provided a little higher but consistent value of exposure than the Hamilton procedure.
4. We are grateful to an anonymous referee for this suggestion.
5. Blackburne and Frank (2007) start the derivation of Equation (5) from the standard autoregressive distributed lag (ARDL) specification in the form $y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} x_{i,t-j} + \mu_i + \in_{it}$, where the number of groups is $i = 1, 2, \ldots, N$; the number of periods is $t = 1, 2, \ldots, T$; x_{it} is a $k \times 1$ vector of explanatory variables; δ_{it} are the $k \times 1$ coefficient vectors; λ_{ij} are scalars, and μ_i is the group specific effect. If the variables in the ARDL model are, for example, I(1) and cointegrated, then the error term is an I(0) process for all i. As stated by Blackburne and Frank (2007), too, a principal feature of cointegrated variables is their responsiveness to any deviation from long-run equilibrium. This feature implies an error correction model in which the short-run dynamics of the variables in the system are influenced by the deviation from equilibrium. Hence, it is common to re-parameterize the ARDL model to the one given here in Equation (5).
6. Available at https://www.worldbank.org/en/research/commodity-markets.
7. See Online Appendix D for a detailed description of the variables.
8. The United Nations Conference on Trade and Development (UNCTAD 2019) state of commodity dependence report categorizes a country as commodity dependent if more than 60% of its total merchandise exports constitute of commodities during the period 2013–2017.
9. The groupings are reported in Online Appendix B. Henceforth Tables B.1, C.1, etc. and Figures B.1, C.1, etc. denote the results reported in the Online Appendix B, C, etc., respectively.
10. See the results for all the other country groupings and setups reported in the Online Appendix C.
11. We performed a robustness check using the standard HP filtering approach for all our analyses. However, we only report the results based on the Hamilton (2018) filtering approach. The results based on the HP filtering data are available upon request.

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APPENDIX 2.A

This section contains the supplementary results from the first essay published under the title "Assessing the Commodity Market Price and Terms of Trade Exposures of Macroeconomy in Emerging and Developing Countries" in the journal Emerging Markets Finance and Trade, volume 58, issue 8, pages 2243-2257. Tables and Figures in this appendix are labelled as it is cited in the published article.

Table B.2. List of countries grouped according to their geographic region, production structure and exchange rate arrangement (regimes)

Geographical grouping			Commodity market dependence grouping				Countries exchange rate regimes				
Africa	Asia	Latin & Caribbean	Agricultural products'	Energy	Minerals	Non	Conventional peg	Floating	SAR	CLA	Other managed
Algeria	Bangladesh	Bolivia	Brazil	Algeria	Burkina Faso	Bangladesh	Fiji	Brazil	Bolivia	Bangladesh	Algeria
Burkina Faso	China	Brazil	Central African Rep.	Bolivia	Burundi	China		Chile	Guatemala	Burundi	Gambia, The
Burundi	Fiji	Chile	Cote d'Ivoire	Cameroon	Chile	Costa Rica	*WAEMU*	Colombia	Indonesia	China	Sudan
Cameroon	India	Colombia	Ecuador	Colombia	Ghana	Dominican Rep.	Burkina Faso	Ghana	Kenya	Costa Rica	
Central African Rep.	Indonesia	Costa Rica	Fiji	Gabon	Mauritania	El Salvador	Côte d'Ivoire	India	Malawi	Dominican Rep.	
Cote d'Ivoire	Malaysia	Dominican Rep.	Gambia, The	Nigeria	Niger	India	Guinea Bissau	Madagascar	Nigeria	Mauritania	
Gabon	Pakistan	Ecuador	Guatemala	Sudan	Peru	Indonesia	Niger	Malaysia	Pakistan	Rwanda	
Gambia, The	Philippines	El Salvador	Guinea-Bissau		Rwanda	Malaysia	Senegal	Mexico		Sri Lanka	
Ghana	Sri Lanka	Guatemala	Kenya		Togo	Mexico	Togo	Paraguay			*No regime*
Guinea-Bissau	Thailand	Mexico	Madagascar			Pakistan		Peru			Panama
Kenya		Panama	Malawi			Panama	*CEMAC*	Philippines			Ecuador
Madagascar		Paraguay	Paraguay			Philippines	Cameroon	South Africa			El Salvador
Malawi		Peru	Senegal			South Africa	Central African Rep.	Thailand			
Mauritania		Uruguay	Uganda			Sri Lanka	Gabon	Uganda			
Niger			Uruguay			Thailand		Uruguay			
Nigeria											
Rwanda											
Senegal											
South Africa											
Sudan											
Togo											
Uganda											
22	10	14	15	7	9	15	10	15	7	8	6

Notes: This table reports the list of countries covered in this study grouped based on their geographical structure, production structure and exchange rate arrangement (regimes). The commodity market dependence groupings are based on UNCTAD (2019) state of commodity dependence report. The exchange regimes are based on IMF (2018) annual report on exchange arrangements and restrictions, and Ilzetzki, Reinhart and Rogoff (2019). SAR = stabilized arrangements regime, CEMAC = Central African Economic and Monetary Community, WAEMU = West African Economic and Monetary Union, CLA = Crawl-like arrangement.

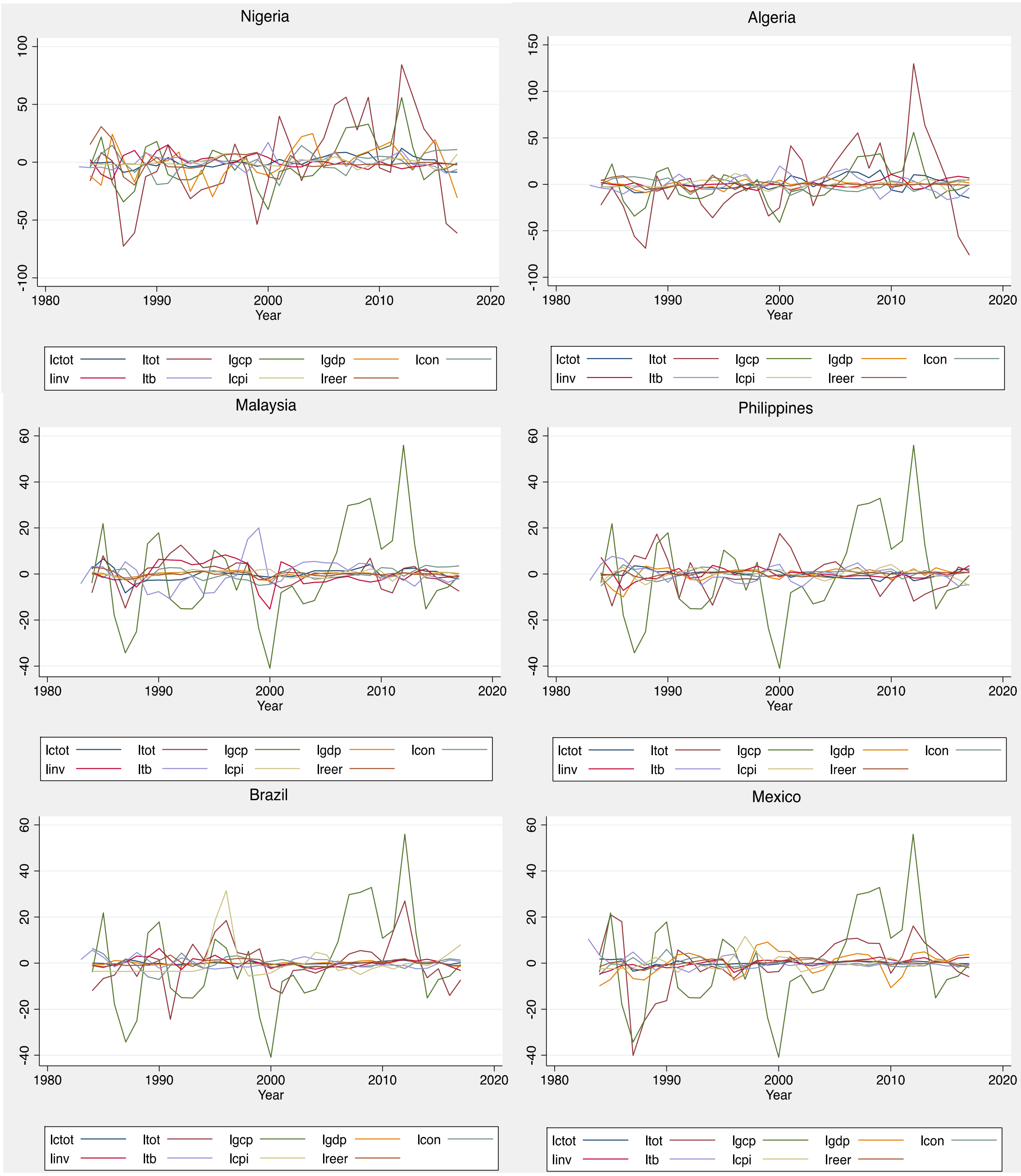

Figure B.1. Cyclical component of variables for some selected countries

Notes: Cyclical component extracted using Hamilton (2018) filter for the log values of the annual data for some selected economies. Notations are for the cyclical components of the following variables: lctot = log of commodity terms of trade, ltot = log of standard terms of trade, lgcp= log of global commodity price index, lgdp = log of gdp (output), lcon = log of private consumption, linv= log of private investments, ltb = log of trade balance, lcpi = log of consumer price index.

Table B.3. Descriptive statistics of geographical and market grouping

	1	2	3	4	5	6	7	8	9	10	11
Panel A	Output										
	m_y	σ_y	$\rho(1)_y$	$\rho_{y,ctot}$	$\rho_{y,tot}$	$\rho_{y,gcp}$	$\rho_{y,c}$	$\rho_{y,inv}$	$\rho_{y,tb}$	$\rho_{y,cpi}$	$\rho_{y,er}$
Africa	0.00	10.563	0.46	-0.03	0.11	0.04	-0.09	0.09	-0.07	0.02	-0.05
Asia	0.00	0.854	0.50	1.00	0.19	0.16	-0.25	0.16	0.13	0.22	0.28
Latin & Caribbean	0.00	1.813	0.47	1.00	0.11	0.17	-0.10	0.18	0.06	0.02	0.03
Emerging markets	0.00	0.935	0.49	0.12	0.19	0.19	-0.29	0.22	-0.13	-0.20	0.24
Developing markets	0.00	9.870	0.48	0.01	0.05	0.09	-0.05	0.06	-0.03	0.01	-0.01
	Consumption										
Panel B	m_c	σ_c	$\rho(1)_c$	$\rho_{c,ctot}$	$\rho_{c,tot}$	$\rho_{c,gcp}$	$\rho_{c,y}$	$\rho_{c,inv}$	$\rho_{c,tb}$	$\rho_{c,cpi}$	$\rho_{c,er}$
Africa	0.00	7.11	0.43	-0.22	-0.09	-0.06	-0.09	-0.11	-0.07	0.02	0.07
Asia	0.00	2.95	0.43	-0.16	-0.16	0.07	-0.25	-0.10	0.01	0.15	-0.04
Latin & Caribbean	0.00	2.96	0.43	-0.32	-0.32	-0.12	-0.10	-0.18	-0.21	0.09	0.05
Emerging markets	0.00	2.22	0.45	-0.32	-0.39	-0.20	-0.29	-0.14	-0.09	0.24	0.04
Developing markets	0.00	6.17	0.43	-0.22	-0.10	-0.03	-0.05	-0.12	-0.07	0.02	0.07
	Investments										
Panel C	m_i	σ_i	$\rho(1)_i$	$\rho_{i,ctot}$	$\rho_{i,tot}$	$\rho_{i,gcp}$	$\rho_{i,y}$	$\rho_{i,c}$	$\rho_{i,tb}$	$\rho_{i,cpi}$	$\rho_{i,er}$
Africa	0.00	4.83	0.41	-0.11	-0.05	0.06	0.09	-0.11	-0.21	-0.04	-0.07
Asia	0.00	3.17	0.46	-0.18	-0.04	0.10	0.16	-0.10	-0.24	-0.09	0.11
Latin & Caribbean	0.00	2.48	0.51	-0.05	0.01	0.14	0.18	-0.18	-0.23	0.11	0.08
Emerging markets	0.00	2.78	0.48	-0.03	-0.03	0.18	0.22	-0.14	-0.34	-0.06	0.15
Developing markets	0.00	4.26	0.42	-0.12	-0.04	0.06	0.06	-0.12	-0.20	-0.03	-0.06
	Trade balance										
Panel D	m_{tb}	σ_{tb}	$\rho(1)_{tb}$	$\rho_{tb,ctot}$	$\rho_{tb,tot}$	$\rho_{tb,gcp}$	$\rho_{tb,y}$	$\rho_{tb,c}$	$\rho_{tb,inv}$	$\rho_{tb,cpi}$	$\rho_{tb,er}$
Africa	0.00	5.86	0.40	0.14	0.08	-0.04	-0.07	-0.07	-0.21	0.02	-0.02
Asia	0.00	3.77	0.48	0.02	0.06	-0.10	-0.13	0.01	-0.24	0.10	-0.15
Latin & Caribbean	0.00	3.21	0.45	0.13	0.12	-0.03	-0.06	-0.21	-0.23	-0.13	-0.09
Emerging markets	0.00	3.41	0.49	0.06	0.03	-0.09	-0.13	-0.09	-0.34	0.02	-0.21
Developing markets	0.00	5.19	0.41	0.13	0.10	-0.04	-0.03	-0.07	-0.20	0.02	-0.02
	Consumer price index										
Panel E	m_{cpi}	σ_{cpi}	$\rho(1)_{cpi}$	$\rho_{cpi,ctot}$	$\rho_{cpi,tot}$	$\rho_{cpi,gcp}$	$\rho_{cpi,y}$	$\rho_{cpi,c}$	$\rho_{cpi,inv}$	$\rho_{cpi,tb}$	$\rho_{cpi,er}$
Africa	0.00	15.11	0.21	0.01	-0.03	0.01	0.02	0.02	-0.04	0.02	-0.01
Asia	0.00	4.32	0.47	-0.16	-0.05	0.13	-0.22	0.15	-0.09	0.10	-0.18
Latin & Caribbean	0.00	4.19	0.49	-0.13	-0.04	0.08	0.02	0.09	0.11	-0.13	-0.09
Emerging markets	0.00	3.87	0.48	-0.13	-0.09	0.07	-0.20	0.24	-0.06	0.02	-0.12
Developing markets	0.00	12.62	0.23	-0.01	-0.02	0.02	0.01	0.02	-0.03	0.02	-0.01
	Real effective exchange rate										
Panel F	m_{er}	σ_{er}	$\rho(1)_{er}$	$\rho_{er,ctot}$	$\rho_{er,tot}$	$\rho_{er,gcp}$	$\rho_{er,y}$	$\rho_{er,c}$	$\rho_{er,inv}$	$\rho_{er,tb}$	$\rho_{er,cpi}$
Africa	0.00	113.52	-0.04	0.01	0.03	0.00	-0.05	0.07	-0.07	-0.02	-0.01
Asia	0.00	11.12	0.43	0.07	0.13	0.30	0.28	-0.04	0.11	-0.15	-0.18
Latin & Caribbean	0.00	21.28	0.37	0.15	0.17	0.09	0.03	0.05	0.08	-0.09	-0.09
Emerging markets	0.00	11.91	0.43	0.18	0.18	0.30	0.24	0.04	0.15	-0.21	-0.12
Developing markets	0.00	93.60	-0.03	0.02	0.03	0.00	-0.01	0.07	-0.06	-0.02	-0.01

Notes: The table reports the summary statistics for the cyclical component of the Hamilton (2018) filter based on geographic and market structure of the groups for the sample period 1980-2017. *m* denotes mean, standard deviation, the first order autocorrelation and, denotes the cross-correlation between the macro variable *a* and *b*. The macro variables are the aggregate output (*y*), private consumption (*c*), private investments (*i*), the trade balance (*tb*), the consumer price index (*cpi*), and the real effective exchange rate (*er*). The world market price variables are the commodity terms of trade (*ctot*), the standard terms of trade (*tot*), and the global commodity market price index (*gcp*).

Table B.3. Descriptive statistics of production and trade grouping

	1	2	3	4	5	6	7	8	9	10	11
Panel A						Output					
	m_y	σ_y	$\rho(1)_y$	$\rho_{y,ctot}$	$\rho_{y,tot}$	$\rho_{y,gcp}$	$\rho_{y,c}$	$\rho_{y,inv}$	$\rho_{y,tb}$	$\rho_{y,cpi}$	$\rho_{y,er}$
Agricultural products	0.00	9.32	0.48	0.05	0.07	0.12	-0.05	0.07	-0.02	0.01	-0.04
Minerals	0.00	3.32	0.37	0.13	0.04	0.10	-0.09	0.12	-0.05	0.08	0.00
Energy	0.00	4.92	0.47	0.03	0.11	0.19	-0.05	0.15	-0.08	0.00	0.01
Non-commodity	0.00	5.18	0.49	0.04	0.17	0.14	-0.23	0.15	-0.13	-0.19	0.23
Comm. importers	1.49	7.26	0.46	0.02	0.13	0.16	-0.09	0.19	-0.09	0.03	0.00
Comm. exporters	-0.48	6.26	0.48	0.04	0.08	0.12	-0.08	0.09	-0.05	-0.03	0.01
Panel B						Consumption					
	m_c	σ_c	$\rho(1)_c$	$\rho_{c,ctot}$	$\rho_{c,tot}$	$\rho_{c,gcp}$	$\rho_{c,y}$	$\rho_{c,inv}$	$\rho_{c,tb}$	$\rho_{c,cpi}$	$\rho_{c,er}$
Agricultural products	0.00	6.86	0.48	-0.12	0.03	0.02	-0.05	0.08	-0.01	0.10	0.12
Minerals	0.00	6.01	0.31	-0.16	-0.13	-0.12	-0.09	-0.36	-0.06	-0.13	0.06
Energy	0.00	5.28	0.47	-0.46	-0.42	-0.19	-0.05	-0.15	-0.22	0.02	0.22
Non-commodity	0.00	2.54	0.41	-0.24	-0.19	0.00	-0.23	-0.22	-0.08	0.11	0.00
Comm. importers	0.00	4.34	0.33	-0.32	-0.18	-0.09	-0.09	-0.14	-0.08	-0.14	0.10
Comm. exporters	0.00	5.65	0.45	-0.20	-0.11	-0.04	-0.08	-0.12	-0.07	0.05	0.07
Panel C						Investments					
	m_i	σ_i	$\rho(1)_i$	$\rho_{i,ctot}$	$\rho_{i,tot}$	$\rho_{i,gcp}$	$\rho_{i,y}$	$\rho_{i,c}$	$\rho_{i,tb}$	$\rho_{i,cpi}$	$\rho_{i,er}$
Agricultural products	0.00	3.85	0.42	-0.18	0.01	0.13	0.07	0.08	-0.18	-0.12	-0.11
Minerals	0.00	5.17	0.42	0.03	-0.02	0.08	0.12	-0.36	-0.19	0.16	-0.05
Energy	0.00	3.98	0.42	-0.22	-0.19	-0.08	0.15	-0.15	-0.28	-0.05	-0.15
Non-commodity	0.00	2.92	0.49	-0.07	0.02	0.13	0.15	-0.22	-0.27	-0.03	0.09
Comm. importers	-0.15	3.08	0.42	-0.19	0.02	0.04	0.19	-0.14	-0.26	0.12	0.02
Comm. exporters	0.05	4.13	0.43	-0.09	-0.06	0.09	0.09	-0.12	-0.21	-0.05	-0.06
Panel D						Trade balance					
	m_{tb}	σ_{tb}	$\rho(1)_{tb}$	$\rho_{tb,ctot}$	$\rho_{tb,tot}$	$\rho_{tb,gcp}$	$\rho_{tb,y}$	$\rho_{tb,c}$	$\rho_{tb,inv}$	$\rho_{tb,cpi}$	$\rho_{tb,er}$
Agricultural products	-0.03	4.33	0.39	0.13	0.08	-0.09	-0.02	-0.01	-0.18	0.12	-0.03
Minerals	-0.06	6.06	0.38	0.14	0.11	-0.01	-0.05	-0.06	-0.19	-0.10	0.00
Energy	0.01	6.38	0.45	0.13	0.11	0.07	-0.08	-0.22	-0.28	-0.01	-0.17
Non-commodity	-0.01	3.17	0.47	0.10	0.00	-0.17	-0.13	-0.08	-0.27	0.05	-0.16
Comm. importers	-0.10	5.03	0.38	0.12	0.05	-0.01	-0.09	-0.08	-0.26	0.00	-0.08
Comm. exporters	0.00	4.68	0.43	0.12	0.10	-0.07	-0.05	-0.07	-0.21	0.02	-0.03
Panel E						Consumer price index					
	m_{cpi}	σ_{cpi}	$\rho(1)_{cpi}$	$\rho_{cpi,ctot}$	$\rho_{cpi,tot}$	$\rho_{cpi,gcp}$	$\rho_{cpi,y}$	$\rho_{cpi,c}$	$\rho_{cpi,inv}$	$\rho_{cpi,tb}$	$\rho_{cpi,er}$
Agricultural products	0.00	8.78	0.36	-0.01	-0.10	0.03	0.01	0.10	-0.12	0.12	0.00
Minerals	0.00	5.27	0.48	-0.03	0.01	0.11	0.08	-0.13	0.16	-0.10	-0.02
Energy	0.00	23.31	0.13	0.00	0.00	-0.03	0.00	0.02	-0.05	-0.01	-0.02
Non-commodity	0.00	4.17	0.46	-0.20	-0.07	0.13	-0.19	0.11	-0.03	0.05	-0.19
Comm. importers	0.11	5.25	0.45	-0.07	0.01	0.14	0.03	-0.14	0.12	0.00	-0.11
Comm. exporters	-0.03	12.16	-0.01	-0.03	0.01	-0.03	0.05	-0.05	0.02	-0.01	-0.01
Panel F						Real effective exchange rate					
	m_{er}	σ_{er}	$\rho(1)_{er}$	$\rho_{er,ctot}$	$\rho_{er,tot}$	$\rho_{er,gcp}$	$\rho_{er,y}$	$\rho_{er,c}$	$\rho_{er,inv}$	$\rho_{er,tb}$	$\rho_{er,cpi}$
Agricultural products	0.00	27.79	0.57	0.00	0.12	0.00	-0.04	0.12	-0.11	-0.03	0.00
Minerals	0.00	170.07	-0.09	0.02	0.01	-0.01	0.00	0.06	-0.05	0.00	-0.02
Energy	0.00	50.63	0.41	0.06	0.07	0.07	0.01	0.22	-0.15	-0.17	-0.02
Non-commodity	-1.95e	10.96	0.43	0.12	0.18	0.25	0.23	0.00	0.09	-0.16	-0.19
Comm. importers	0.11	5.25	0.45	0.11	0.19	0.00	0.00	0.10	0.02	-0.08	-0.11
Comm. exporters	-0.03	12.16	0.22	0.01	0.03	0.02	0.01	0.07	-0.06	-0.03	-0.01

Notes: The table reports the summary statistics for the cyclical component of the Hamilton (2018) filter based on their commodity market dependence (i.e., agricultural products, minerals, energy, non-commodity dependent), commodity exporters, and importers for the sample period 1980-2017. For the notations see Table B.2.

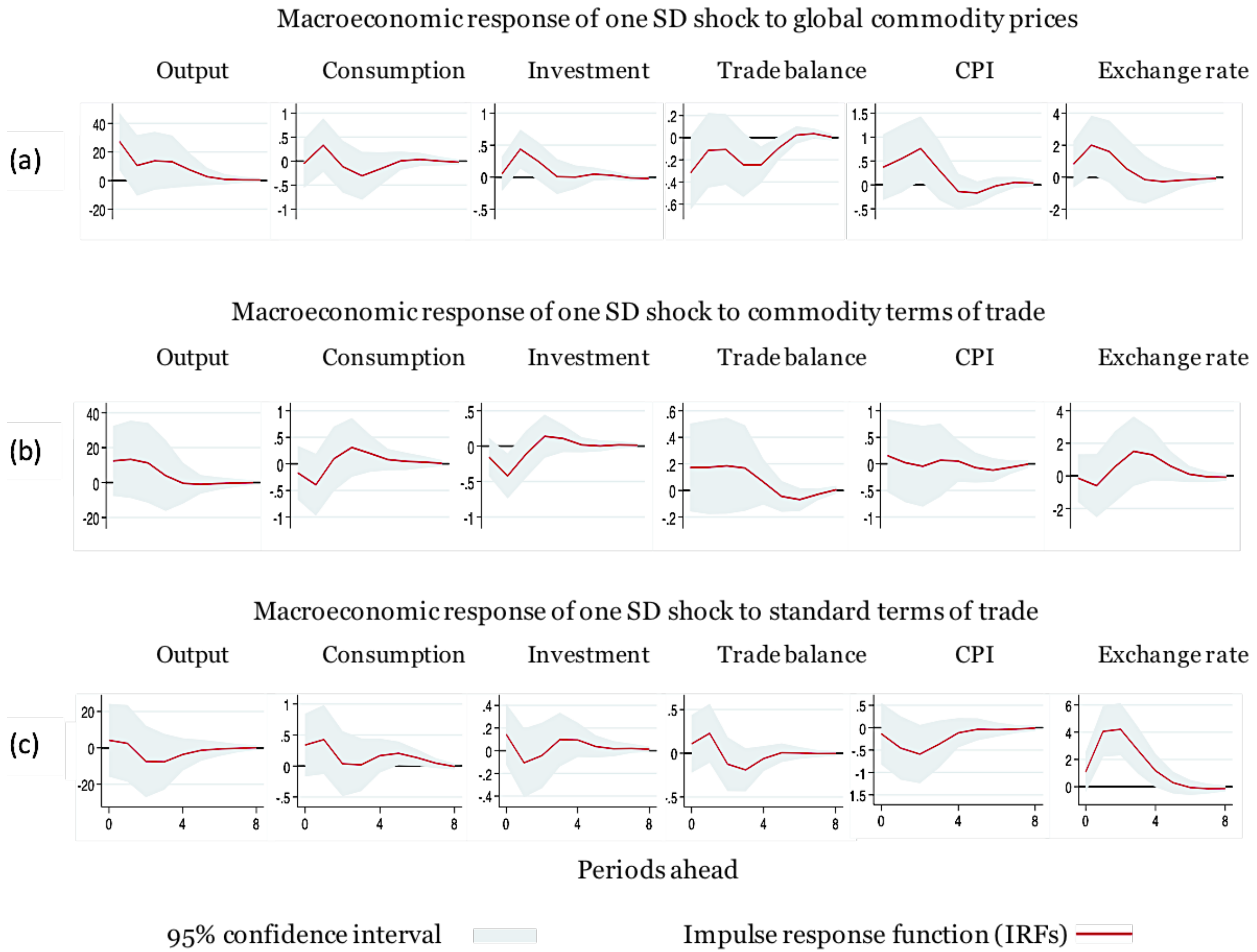

Figure C.1. Impulse responses for the agricultural products' dependent economies
Source: Authors' calculation based on Eq. (4) of the empirical model and Eqs. (18) – (33) of the theoretical model.

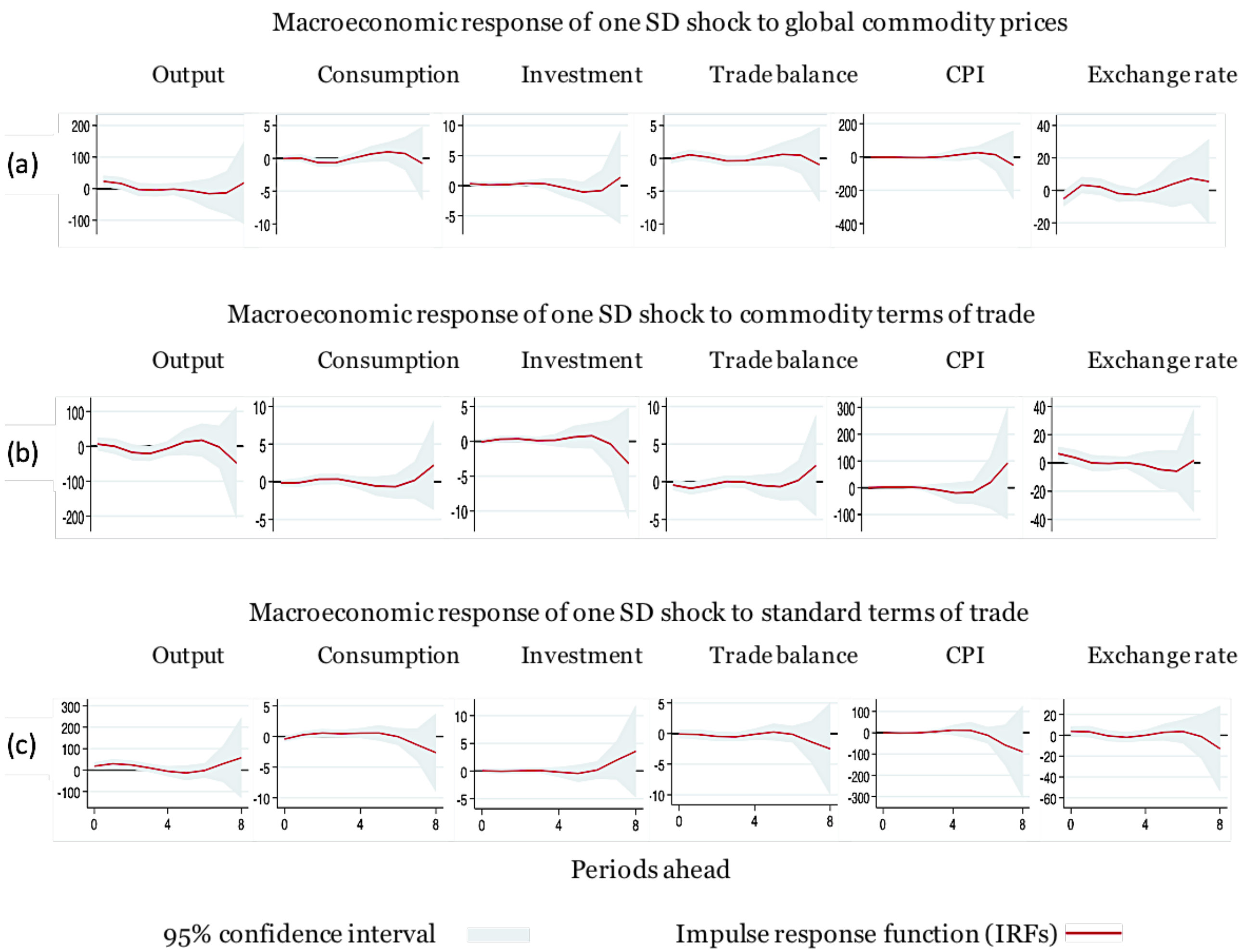

Figure C.2. Impulse responses for the energy dependent economies
Source: Authors' calculation based on Eq. (4) of the empirical model and Eqs. (18) – (33) of the theoretical model

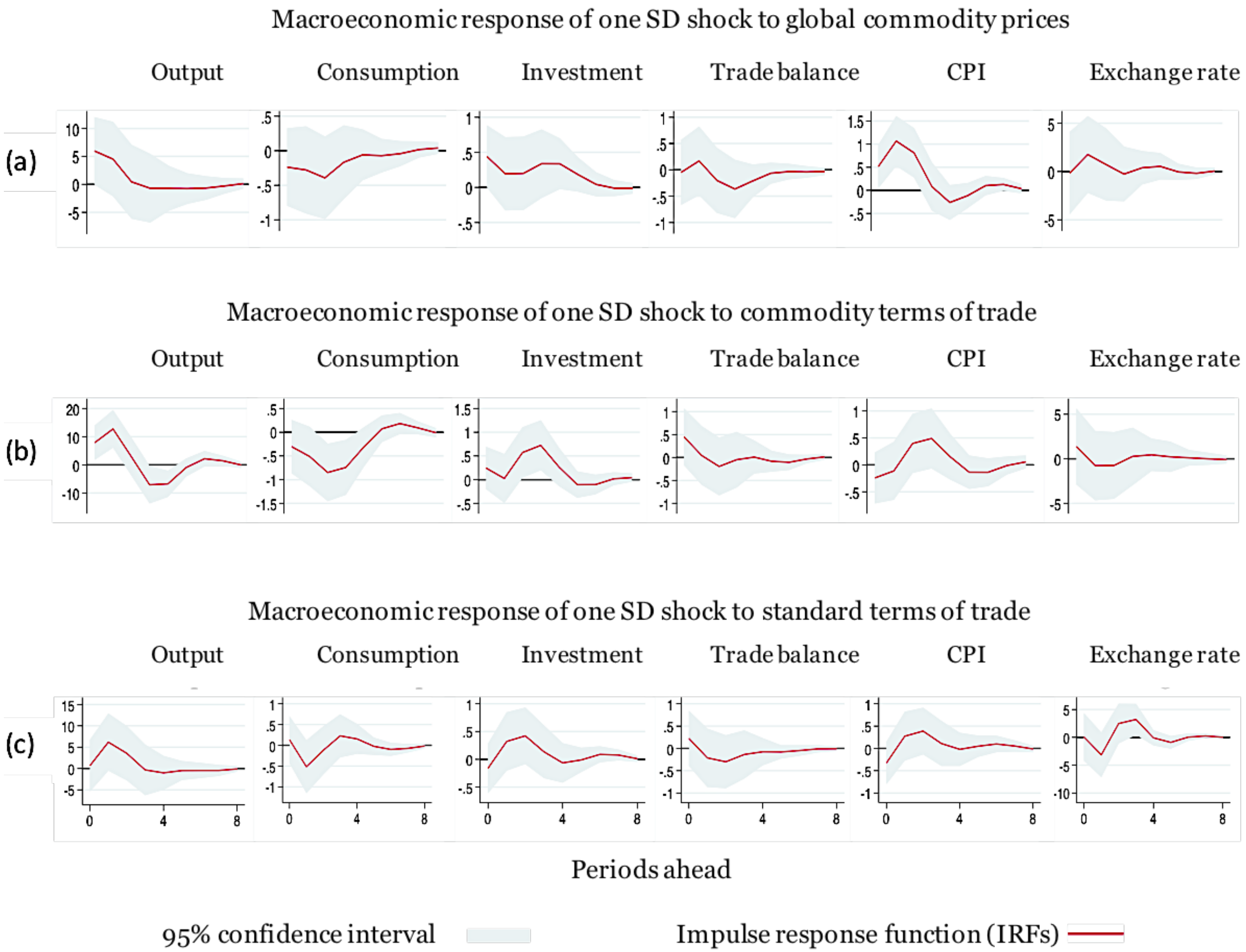

Figure C.3. Impulse responses for the minerals dependent economies
Source: Authors' calculation based on Eq. (4) of the empirical model and Eqs. (18) – (33) of the theoretical model.

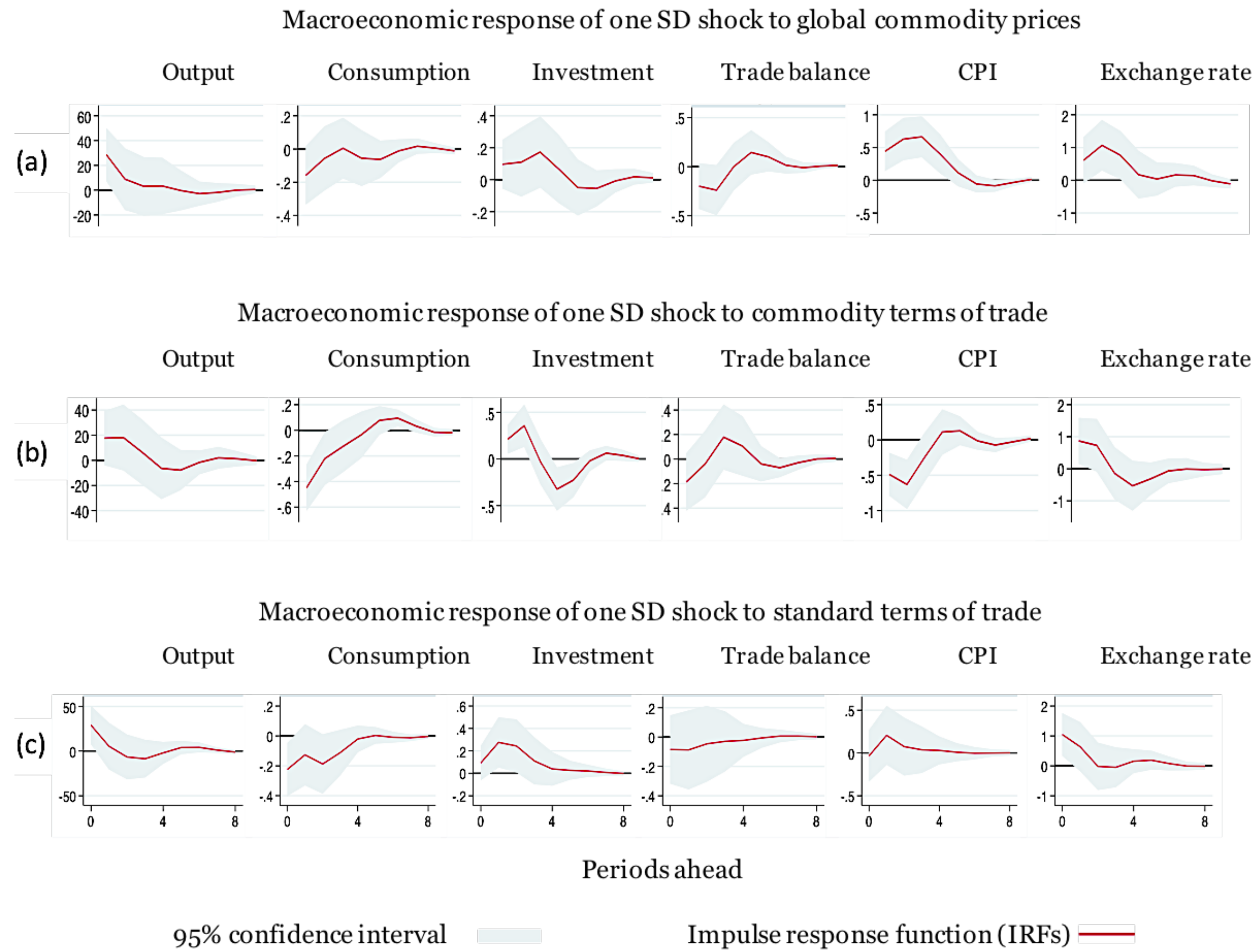

Figure C.4. Impulse responses for the non-commodity dependent economies.

Source*:* Authors' calculation based on Eq. (4) of the empirical model and Eqs. (18) – (33) of the theoretical model.

Table C.1. Forecast-error variance decomposition (FEVD) for Africa and Other economies

	Output			Consumption			Investment			Trade balance			Consumer price index			Exchange rate		
Periods	*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*	*ctot*	*tot*	*gcp*
African economies																		
1	1.83%	0.60%	0.15%	0.09%	0.23%	0.20%	0.09%	0.06%	0.45%	0.17%	0.00%	0.73%	0.01%	0.24%	0.16%	0.03%	0.55%	0.74%
2	1.28%	1.09%	0.78%	0.75%	0.38%	0.16%	0.14%	0.04%	1.15%	0.42%	0.04%	0.60%	0.04%	0.21%	0.36%	0.04%	0.93%	0.72%
3	1.92%	1.51%	1.11%	0.78%	0.48%	0.48%	1.06%	0.12%	1.39%	0.62%	0.24%	0.61%	0.13%	0.20%	0.67%	0.11%	1.89%	0.72%
4	3.59%	1.51%	1.08%	0.78%	0.53%	0.95%	1.75%	0.22%	1.43%	0.63%	0.40%	0.80%	0.10%	0.16%	0.46%	0.19%	2.04%	0.74%
5	4.22%	1.48%	1.08%	0.76%	0.54%	1.02%	1.76%	0.26%	1.46%	0.71%	0.43%	0.98%	0.10%	0.15%	0.51%	0.22%	2.05%	0.75%
Average	**2.57%**	**1.24%**	**0.84%**	**0.63%**	**0.43%**	**0.56%**	**0.96%**	**0.14%**	**1.18%**	**0.51%**	**0.22%**	**0.74%**	**0.08%**	**0.19%**	**0.43%**	**0.12%**	**1.49%**	**0.73%**
Other economies																		
1	1.14%	1.39%	2.07%	4.47%	1.76%	0.02%	0.00%	1.12%	0.38%	0.20%	0.09%	0.08%	1.10%	0.00%	2.57%	1.38%	2.12%	0.06%
2	1.52%	1.44%	1.84%	3.78%	1.59%	0.08%	0.17%	1.45%	0.74%	0.16%	0.07%	0.06%	1.28%	0.51%	4.20%	1.86%	1.83%	2.05%
3	1.52%	1.44%	1.92%	3.54%	1.56%	0.11%	0.19%	1.89%	1.14%	0.21%	0.25%	0.08%	1.32%	0.66%	5.13%	1.92%	1.83%	2.81%
4	1.56%	1.52%	1.97%	3.56%	1.55%	0.11%	0.50%	2.12%	1.38%	0.21%	0.40%	0.10%	1.29%	0.65%	5.17%	1.86%	1.86%	2.73%
5	1.60%	1.53%	1.97%	3.62%	1.56%	0.11%	0.60%	2.12%	1.43%	0.22%	0.42%	0.11%	1.29%	0.66%	5.14%	1.85%	1.89%	2.75%
Average	**1.47%**	**1.46%**	**1.95%**	**3.79%**	**1.60%**	**0.09%**	**0.29%**	**1.74%**	**1.01%**	**0.20%**	**0.25%**	**0.08%**	**1.26%**	**0.50%**	**4.44%**	**1.77%**	**1.90%**	**2.08%**

Table D.2. Results of panel unit root test

	LLC		IPS	
	level	first diff.	level	first diff.
Raw data (full sample)				
Commodity terms of trade index	-1.56	-15.95***	-1.61	-23.26***
Standard terms of trade index	-4.68***		-4.27***	
Global commodity price index	13.87		-0.51	-2.59***
Output	12.37	-13.79***	13.02	-16.65***
Consumption	-2.85***		-4.66***	
Investment	-2.70***		-5.19***	
Trade balance	-3.47***		-6.27***	
Consumer price index	10.15	-4.89***	17.47	-10.18***
Real effective exchange rate	-8.84***		-3.60***	
(log) Hamilton cycle (full sample)				
Commodity terms of trade index	-11.07***		-16.83***	
Standard terms of trade index	-11.29***		-17.91***	
Global commodity price index	-7.92***		-5.98***	
Output	-13.60***		-18.73***	
Consumption	-12.10***		-18.30***	
Investment	-19.65***		-18.61***	
Trade balance	-18.53***		-20.14***	
Consumer price index	-8.47***		-16.06***	
Real effective exchange rate	-12.77***		-18.66***	
Cross sections	46	46	46	46
Observations	1609	1609	1609	1609
African countries (Hamilton cycle)				
Commodity terms of trade index	-9.84***		-9.72***	
Standard terms of trade index	-10.35***		-10.97***	
Global commodity price index	-3.12***		-5.48***	
Output	-10.27***		-10.06***	
Consumption	-12.16***		-12.89***	
Investment	-12.60***		-12.36***	
Trade balance	-13.55***		-13.28***	
Consumer price index	-9.45***		-7.35***	
Real effective exchange rate	-11.97***		-11.37***	
Cross sections	22		22	
Observations	814		814	
Other countries (Hamilton cycle)				
Commodity terms of trade index	-10.05***		-11.28***	
Standard terms of trade index	-10.76***		-12.39***	
Global commodity price index	-3.22***		-5.72***	
Output	-11.38***		-7.69***	
Consumption	-7.64***		-11.99***	
Investment	-13.77***		-9.32***	
Trade balance	-12.58***		-11.61***	
Consumer price index	-8.69***		-5.25***	
Real effective exchange rate	-11.44***		-10.33***	
Cross sections	24		24	
Observations	887		887	

***Notes*:** LLC denotes Levin-Lin-Chu unit root test, IPS denotes Im-Pesaran-Shin unit-root test. LLC assumes a common unit root process, and IPS assumes individual unit root process in the panel, and diff denotes difference. ***Denotes the significance of the test statistics at 1% level

Table D.3. Data description and sources

Series name	Description	Type	Period	Source
Commodity terms of trade (*ctot*) index	Commodity terms of trade index weighted by GDP (2012m6=100)	Country specific	1980-2017	Gruss and Kebhaj (2019); IMF
Global all commodity price index (*gcp*) index	All group commodity market price index (in terms of constant dollars) (2000=100)	General	1980-2016	UNCTADStat
Standard terms of trade (*tot*) index	Net barter terms of trade index (2000 = 100)	Country specific	1980-2017	World Bank WDI
Output (y)	GDP per capita in constant local currency units	Country specific	1980-2017	World Bank WDI
Investment (i)	Gross capital formation (% of GDP)	Country specific	1980-2017	World Bank WDI
Trade balance (tb) *(Export-import)*	Imports of goods and services (% of GDP)	Country specific	1980-2017	World Bank WDI
	Exports of goods and services (% of GDP	Country specific	1980-2017	World Bank WDI
Consumption (con)	Household final consumption expenditure, etc. (% of GDP),	Country specific	1980-2017	World Bank WDI
Consumer price index (*cpi*)	Consumer price index (2010 = 100)	Country specific	1980-2017	World Bank WDI
Real effective exchange rate (*reer*)	Real effective exchange rate index (2005 = 100)	Country specific	1980-2017	World Bank WDI

3 COMMODITY MARKETS AND THE GLOBAL MACROECONOMY: EVIDENCE FROM MACHINE LEARNING AND GVAR

Abstract
This study identifies the most essential commodities in global economy and investigates the connections between commodity markets and global macroeconomic performance. First, we employ machine learning techniques to identify the globally traded commodities whose returns are important to the changes in global macroeconomic activities. Second, we estimate the dynamic effects of these important commodities using a global vector autoregressive (GVAR) model to assess the global economic reactions in greater detail. Our results indicate that of the 55 analyzed commodities, only four are recognized to be the most significant to the development of global macroeconomic indicators. Our GVAR analysis indicates that the commodity market effects on macroeconomic activity are neither unanimous across the commodities nor across macro variables. In effect, the commodity market exposure is considerably stronger among the advanced countries (such as the euro area), other developed economies, and China compared to the emerging economies of Africa, Asia, and Latin America, at both the country and regional levels.

Keywords: commodity prices, macroeconomy, machine learning, global VAR
JEL Codes: C32, E32, F42, Q43

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3.1 Introduction

Commodity market prices are influenced by global macroeconomic cycles, as demonstrated by events such as the 2008-2009 global financial crisis and the recent COVID-19 pandemic. During these crises, commodity prices initially declined but eventually rose as global economic activity recovered. Another notable example is the effect of the war in Ukraine, which highlights the significant impact of macroeconomic conditions on commodity markets. Furthermore, it is widely acknowledged that certain commodities play a more crucial role in economic development, both at a national and global level. Recent evidence based on prices indicates that crises have significant effects on supply chains, particularly in food and energy-related commodity markets. For instance, Stuermer (2018) suggests that the relationship between commodity markets and macroeconomic performance is strongly influenced by demand shocks resulting from changes in global economic activity.

While some researchers have investigated the impact of global economic activity on commodity price changes, others have focused on specific commodities and their relevance to global economic performance (Duarte et al. 2021; Liu, Tan, and Wang 2020; Fasanya and Awodimila 2020; Abbas and Lan 2020; Chen, Rogoff, and Rossi 2010; Kilian 2009; etc.). However, these studies have yet to reach a consensus on which commodities have the most significant price effects on the global economy. Consequently, there remain key questions regarding which commodities, among the many traded globally, are most important for driving global economic activities and promoting economic development in different regions. The present study aims to address this gap by not only identifying the most significant commodities for the global economy but also examining their roles within different countries and groups.

In our study, we propose a novel approach to address these questions. Firstly, we employ machine learning techniques, specifically the Least Absolute Shrinkage and Selection Operator (LASSO) estimation procedure, to determine the time-varying significance of the most important commodity markets' price developments in relation to various macroeconomic indicators. Unlike previous studies that pre-selected specific commodities based on their perceived relevance to macroeconomic indicators, we avoid this bias by letting the data-driven LASSO technique identify the key commodities for the global economy. Secondly, we utilize a global vector autoregressive (GVAR) analysis to examine the dynamic interactions and the speed at which economies adjust to the most relevant commodity market exposures identified through the LASSO estimation procedure. This analysis provides insights into the interdependence between commodity market developments and macroeconomic performance across different countries and groups.

By combining these two techniques, we aim to provide a comprehensive understanding of the significance of various commodities for the global economy, without any a priori assumptions or pre-selection biases. This approach allows for a more robust and objective assessment of the relationship between commodity prices and macroeconomic indicators.

Empirical relationships between specific commodity prices and global economic activities have received considerable scholarly attention. Numerous studies have pointed to the significance of oil price changes in indicating real output changes at both country and global levels (Ge and Tang 2020; Cunado, Jo, and Gracia 2015; Boschi and Girardi 2011). Additionally, research has focused on examining whether commodity prices act as leading indicators for exchange rate movements in commodity-dependent economies, commonly known as commodity currencies. This includes countries such as Australia, Canada, New Zealand, Norway, and South Africa (Beckmann, Czudaj, and Arora 2020; Liu, Tan, and Wang 2020; Baghestani, Chazi, and Khallaf 2019; Chen et al. 2010; Ferraro, Rogoff, and Rossi 2015). Furthermore, extensive analysis has been conducted on the relationship between commodity market exposure and aggregate inflation rates (Fasanya and Awodimila 2020; Abbas and Lan 2020; Gelos and Ustyugova 2017; Chen, Turnovsky, and Zivot 2014). These studies generally agree that global commodity prices can serve as leading indicators for inflation, especially in countries heavily reliant on commodity exports.

The GVAR framework has also been used to explore the impact of commodity prices on the global macroeconomy. Within this framework, research has highlighted the significant role of food prices, including wheat, in the global cycles (Gutierrez and Piras 2013; Galesi and Lombardi 2009). Furthermore, extensive research has been conducted on the global effects of commodity prices, with particular emphasis on energy prices, especially oil, within the GVAR framework. Studies such as Bettendorf (2017), Chudik and Fidora (2012), Boschi and Girardi (2011), Pesaran, Schuermann, and Weiner (2004), Dées, di Mauro, Pesaran, and Smith (2007), and Cashin et al. (2014) have focused on oil prices. For instance, Boschi and Girardi (2011) identified oil prices as a global indicator in explaining output variability in the Euro area, Latin America, and several major individual economies. Chudik and Fidora (2012) used oil prices to analyze the effects of a strong oil supply shock in a GVAR model comparing the real outputs of various emerging economies to those of advanced economies. They observed a negative impact on real GDP growth in oil-exporting economies, as well as changes in the real exchange rates for oil exporters and importers.

These studies provide valuable insights into the role of commodity prices, particularly oil prices, in the global macroeconomy within the GVAR framework. However, an analysis of the existing empirical studies reveals that only a limited number of individual commodities have been examined, based on subjective judgments of their importance. These studies often generalize their findings to global practical analyses or forecasting purposes. While we do not dispute the significance of the commodities that have been investigated, it is crucial to acknowledge the numerous traded commodities worldwide, many of which might have been overlooked despite their potential importance. Assuming that only a few of these commodities are globally significant, as suggested by Duarte et al. (2021) and Baghestani et al. (2019), without employing an appropriate model to determine their actual roles, seems unrealistic. Therefore, we consider a comprehensive range of commodities as potentially influential and aim to identify the most significant ones in relation to global macro variables, such as real GDP, real exchange rate, and inflation.

We understand that other studies, such as Ge and Tang (2020), have examined the connection between commodity market returns and GDP growth using data from 27 commodity futures markets. Liu et al. (2020) investigated 17 commodities, while Jacks and Stuermer (2020) analyzed 12 agricultural goods, metals, and soft commodities from 1870 to 2013. However, in addition to analyzing the spot market price (indices) of 59 commodities, our study employs different data and methodologies. By scrutinizing a large number of individual commodities and utilizing specific methodological choices, we aim to present novel findings on the roles that different commodities play in shaping global economic indicators.

With regards to the empirical methods employed, this paper makes several significant contributions to the existing literature. Firstly, unlike previous studies that made ad hoc selections or assumptions regarding the importance of specific commodities, we consider all 55 individual commodities traded on a daily basis to be equally important. This approach ensures that no prior judgments are made, allowing for a more comprehensive analysis. Secondly, we utilize machine learning techniques to identify the most important commodities among the large set of globally traded individual commodities. This is in contrast to existing studies that often hand-pick only a limited number of commodities based on subjective reasoning. By employing machine learning, we enhance the objectivity and accuracy of our analysis. Lastly, we employ the Global Vector Autoregression (GVAR) model, which combines country-level time series panel data and factor analytic techniques. This model enables us to assess the impact of unit shocks on the identified globally important commodity markets and examine how these shocks are transmitted among different countries and groups of countries. By analyzing the reactions of various regions such as Africa, Asia, the euro area, Latin America, the Middle East, as well as individual large countries like the UK, China, and the US, we gain valuable insights into the transmission mechanisms and dynamics of these shocks.

Based on global data from 1990Q1 to 2019Q4, our analysis reveals that among the 55-commodity market returns data considered, copper, crude oil, gold, and lead markets are the most important for the development of global macroeconomic variables. Specifically, we find that changes in copper and crude oil prices have a significant impact on global output changes. Additionally, changes in gold and lead prices exhibit a strong correlation with real exchange rate changes. The results support the traditional view that the global oil market plays a crucial role in transmitting inflationary pressures across the global economy. This is in line with previous studies (e.g., Ha, Kose, and Ohnsorge, 2022; Herwartz and Plödt, 2016). The importance of copper and oil price changes on output improvement is consistent with findings from other research (e.g., Wen, Zhao, and Hu, 2019; Boschi and Girardi, 2011), suggesting that a shock to these commodity prices leads to a significant increase in real GDP for both advanced and emerging economies.

Furthermore, we observe that a positive shock to gold and lead price changes results in a significant depreciation in the real exchange rate. Considering the current global economic conditions, particularly influenced by the conflict in Ukraine, our analysis suggests that oil price shocks will likely continue to transmit inflationary pressures worldwide for an extended period. However, it is important to note that the effects are not unanimous across different commodities, countries, or macro variables. In addition, we provide evidence that commodity market price exposure is significantly stronger among advanced countries, such as those in the euro area, other developed economies, and China. We also observed less sizable effects for emerging economies, including those in Africa, Asia, and Latin America, both at the national and regional levels. Our findings generally support the significance of several traditional commodities in the global economy, such as crude oil, copper, and gold. However, we also identify an additional commodity, lead metal, that emerges as a significant factor affecting the economic performance of the euro area and several advanced countries. These finding highlights the dynamic nature of commodity markets and the need to consider a range of commodities when analyzing their impact on the global economy.

Overall, these results indicate that commodity market exposure is a significant and prevalent phenomenon in the markets. Therefore, given this significance, implementing policies that mitigate price volatility in these specific commodities can help in smoothing global economic performance. We strongly recommend the adoption of such policies.

The paper is organized as follows: Section 3.2 introduces the empirical models used in this study and provides a description of the data employed. In Section 3.3, a comprehensive discussion of the empirical results is presented. Finally, Section 3.4 concludes the study with a summary of the findings and potential implications.

3.2 Methodology and data

3.2.1 Empirical background

The empirical framework employed in this paper consists of two key stages. In the first stage, the objective is to identify the essential commodity market price/return data that significantly influence global output (real GDP), inflation, and real exchange rate changes. To achieve this, a LASSO machine learning approach is implemented. In the second stage, the focus is on exploring how global macroeconomic variables react to unexpected price fluctuations in the essential commodities identified in the first stage. This is accomplished by utilizing the GVAR (Global Vector Autoregression) framework.

3.2.1.1 The machine learning model

We employed a dataset comprising N observations for a set of variables denoted as $\{(x_t^m, y_{it}^j) \mid t = 1, 2, \ldots\ldots, n\}$. In this context x_t^m represents an input vector consisting of 59 global commodity indices, while y_{it}^j represents a vector of associated response variables (j = real GDP, inflation, and real exchange rate) for each country i. The dimensionality, m, of the input vector is relatively high for standard econometric methods like OLS, which can lead to overfitting issues (Hastie, Tibshirani, and Wainwright, 2015). To address this concern and considering our lack of precise knowledge or prior judgment regarding the set features X for each y^j, it becomes necessary to regularize or constrain the estimation process. To this end, we have utilized a shrinkage estimation procedure known as the Least Absolute Shrinkage and Selection Operator (LASSO), introduced by Tibshirani in 1996. The choice of this model was driven by its capability to handle estimation problems involving high-dimensional input vectors, allowing for prediction and variable selection (Bühlmann and van de Geer, 2011).

The LASSO (Least Absolute Shrinkage and Selection Operator) is a regularization technique that is commonly used in statistical modeling and machine learning. It aims to produce a parsimonious model by shrinking the coefficients of less relevant variables to zero, effectively selecting a subset of variables that have the most significant effects on the response variables. To fit a LASSO-regularized model, a least-squares optimization is performed. The model minimizes a loss function, which is typically a combination of a sum of squared errors term (to match the observed response variable) and a penalization term (to control for the size of the coefficients) as

$$\underset{\beta \in \mathbb{R}^m}{minimize,} \left\{ \frac{1}{2N} \sum_{t=1}^{N} \left(y_{it}^j - \sum_{j=1}^{m} x_t^m \beta^j \right)^2 \right\} \text{ subject to } \sum_{j=1}^{m} |\beta^j| \leq R, \quad (1)$$

where R can be considered the bound that restricts the sum of the absolute values of β^j.

The optimization problem can be rewritten succinctly in a matrix and Lagrangian form as

$$\underset{\beta \in \mathbb{R}^m}{minimize,} \left\{ \frac{1}{2N} \|Y - \boldsymbol{X}\beta\|_2^2 + \lambda \|\beta\|_1 \right\} \quad (2)$$

where $\|y - X\beta\|_2^2 = \sum_{i=1}^{N} (Y - (\boldsymbol{X}\beta))^2$, and $\|\beta\|_1 = \sum_{j=1}^{m} |\beta_j|$.

This setting utilizes a one-to-one relationship between the variables R and λ, where λ≥0 represents a penalty or shrinkage parameter. The term $\lambda\|\beta\|_1$ controls the complexity of the model and enables the LASSO algorithm to perform model selection by excluding statistically insignificant covariates[7]. During the variable selection phase, the LASSO algorithm selects λ through cross-validation, evaluating a range of λ values and their corresponding predictors to minimize the cross-validation (CV) or prediction error (mean squared error (MSE)).

In cross-validation, the LASSO procedure divides the dataset randomly into K = 10 folds, utilizing one-fold as the test dataset and the remaining K-1 folds as the training dataset. The LASSO optimization problem is then applied to the K-1 dataset using different λ values to predict the test set and record the MSE. This process is repeated K times until the average λ yielding the minimum CV is found, along with the corresponding coefficients β. In LASSO, the shrinkage parameter (also known as lambda) is used to control the amount of regularization applied which helps in finding the right balance between model complexity and predictive performance. For more in-depth discussions on LASSO, please refer to the works of Tibshirani and Wainwright (2015), Bühlmann and van de Geer (2011), and Tibshirani (1996).

We employed the adaptive LASSO selection method, which involves multiple steps. The adaptive approach uses 10 folds of cross-validation (CV) to select an optimal lambda [λ^*] through a two-step LASSO process. In the first step, a λ^* value is chosen, and the penalty weights are derived from the parameter estimates. These weights are then utilized in the second step to select another λ^* value that minimizes prediction error. The adaptive method is ideally suited for situations where LASSO is used for model selection, as in our case. Moreover, it is more robust compared to the ordinary (one-step) LASSO procedure.

In our application, we employ a two-stage estimation process. In the first stage, we focus on model selection by utilizing adaptive LASSO algorithms. These algorithms are employed to identify the model that best aligns with the data generation processes (DGP) of the commodity market and macro variables under consideration. During this stage, the LASSO procedure helps us select the most suitable commodities from a set of potentially m dimensional global commodities returns (X) for each macro response variable, denoted as y^j for each country, denoted as i. By utilizing the adaptive LASSO approach discussed earlier, we estimate the model based on this selection process.

$$\mathbf{E}\left[\Delta y_i^j | \Delta X\right] = \beta^j \Delta x^m, \tag{3}$$

where Δy_i^j denotes changes in the response variable j for each country i, and Δx^m = (log) changes in the 59 global commodity price indices. From this initial

[77] To address multicollinearity in the LASSO estimation, certain variables were excluded from the model, namely the natural gas prices for the US and EU, as well as the prices of Brent and Dubai crude oil. The decision was made due to the high level of static correlation observed among these energy market time series. When variables are collinear, meaning they have a strong correlation, the LASSO regression may arbitrarily select one of these highly correlated commodities while dropping the others in its search for the optimal model (Tibshirani, 1996). Therefore, to ensure appropriate control of multicollinearity, we conducted an examination of both the static and dynamic (conditional) correlations among the energy market price change series mentioned above. This examination was carried out in Section 3.2.2 before proceeding further.

estimation stage (Stage 1), we identify the most significant commodities, selected through adaptive LASSO, for each macroeconomic response variable (j). However, it's important to note that the selected coefficients (β) for these crucial commodities are presented without standard errors or test statistics. Therefore, no statistical inference can be drawn solely based on these coefficients.

To address this limitation and obtain statistical inference, we proceed to the second stage (Stage 2) of our analysis. In this stage, we employ the parsimonious model obtained from the adaptive LASSO estimation in Stage 1. Here, we regress each commodity selected by adaptive LASSO (refer to them as "A" in Stage 1) on the corresponding response variable y^j f for each country i. This approach allows us to estimate the relationship between the selected commodities and the specific response variables, while also providing statistical inference as

$$\mathbf{E}\left[\Delta y_i^j | \Delta \mathrm{A}\right] = \alpha^j \Delta A, \quad (4)$$

where A consists of variables that have been selected based on their association with the response variables, represented by the estimated coefficient matrix α^j for each response variable j. To ensure the reliability of our results, we employ a robust standard error estimation technique. This technique provides us with consistent coefficient estimates and robust standard errors, which account for potential heteroscedasticity and non-normality in the data. Once we have identified the variables using the adaptive LASSO method, we incorporate them into our subsequent estimation stage, known as the GVAR model. This stage aims to examine the structural dynamic impacts of the selected commodities on the macro variables of interest. By employing these methodologies, we aim to provide robust and reliable insights into the relationship between the selected commodities and the macro variables under investigation.

3.2.1.1.1 The GVAR model

GVAR methodology, which stands for Global Vector Autoregressive modeling, is an innovative approach in macroeconometrics. It integrates time series and panel data features with factor analytic techniques to effectively analyze various economic and financial topics. This methodology is versatile and can be applied to diverse areas such as policy analysis and risk management.

By employing GVAR models, we can examine interactions between different economies and identify global spillover effects. This approach provides a comprehensive framework to understand how shocks in one country or region affect others, allowing policymakers to assess the potential impact of their decisions on the global economy.

In the empirical procedure described, the first step involves estimating a multi-country augmented vector autoregressive (VARX*) model. This model takes into account domestic variables, country-specific foreign variables (X*) weighted by international trade patterns, and global factors such as commodity price changes chosen using the LASSO method. The GVAR model, initially introduced by Pesaran, Schuermann, and Weiner in 2004, has been further developed by Dées, di Mauro, Pesaran, and Smith in 2007. In this study, the model was estimated for a total of 33 countries, including both developed and emerging economies (see Table 1 for more details). In the representation used, the global economy consists of *N + 1* countries, indexed by *i = 0, 1, 2, ..., N*. For each country i, the VARX*(p, q)* model was estimated, where the country-specific macro variables (*j*) are related to their corresponding foreign variables (*j*)* and the changes in global commodity prices are treated as weakly exogenous from the beginning.

Following the methods employed by Gutierrez and Piras (2013), Dées, di Mauro, Pesaran, and Smith (2007), and Pesaran et al. (2004), the dynamic VARX*(*p, q*) model allowing for the inclusion of global variables is given as

$$\boldsymbol{\Phi}_i(L,p)y_{it}^{j} = a_{io}^{j} + a_{i1}^{j}t + \boldsymbol{\Lambda}_i(L,q)y_{it}^{j*} + \boldsymbol{\Psi}_i(L,q)x_t + \epsilon_{it}^{j}, \quad (5)$$

In our specific case, we have the vector y_{it}^{j} = (*real GDP, inflation, real exchange rate*)' which represents the country-specific variables. Here, *i* refers to the country in question, *j* represents the macro variable observed at time t. Additionally, the vector y_{it}^{j*} = (*real GDP*, inflation*, real exchange rate**)' represents the foreign counterparts of these variables, reflecting the macro-level influences exerted by the rest of the world on a given economy *i*. Furthermore x_t represents the vector of global variables, specifically the relevant commodity market returns extracted from the LASSO stage of our analysis. Moreover, $y_{it}^{j*} = \sum_{i}^{N} w_{a,b} y_{it}^{j}$ denotes the weighted average of country-specific variables, where $w_{a,b}$ is based on the trade weight of bilateral trade flows between country *a* and *b*. In the equations $\boldsymbol{\Phi}_i(L,p) = \mathrm{I} - \sum_{t=1}^{p}\boldsymbol{\Phi}_i L^t$, $\boldsymbol{\Lambda}_i(L,q) = \sum_{t=0}^{q}\boldsymbol{\Lambda}_i L^t$ and $\boldsymbol{\Psi}_i(L,q) = \sum_{t=0}^{q}\boldsymbol{\Psi}_i L^t$, we have the corresponding matrix lag polynomials of the unknown coefficients for the macro variable *j* specific to each country *i*. *L* represents the lag operator, and *p* and *q* are the lag orders, which may vary across the country i equations and are selected based on the AIC criteria for each country[8].

Additionally, a_{io} represents a vector of constants, while a_{i1} represents a vector of coefficients on the deterministic trend (t) for each variable *j*. The ϵ_{it}^{j} series represents the error term specific to country i for each macroeconomic variable j, assumed to be independent and identically distributed with a mean of 0 and covariance matrix Σ_{ii} These error terms are allowed to have weak correlations, consistent with the framework proposed by Chudik and Pesaran (2016). Subsequently, the estimated country VARX* (*p, q*) models, as depicted in Equation 5, are stacked and solved simultaneously as a single GVAR model. This modeling approach incorporates trade flows and explicitly considers interdependencies across economies.

Following Chudik and Fidora (2012), we can succinctly write the reduced form as

[8]Appendix A.4 reports the VARX* orders in the country-specific models selected by the AIC.

$$\mathbf{G}y_t = a_o + a_1 t + \mathbf{H}_1 x_{t-1} + \mathbf{H}_1 x_{t-2} + \mathrm{u}_t. \quad (6)$$

In this context, G and H refer to global vector autoregressive (VAR) matrices that are constructed using country trade weights (W). These matrices are used in Eq. 6, which is further explained in the works of Chudik and Pesaran (2016), Pesaran et al. (2004), and Dées et al. (2007). The purpose of using these matrices is to analyze contemporaneous impacts, feedback effects, and conduct forecasting analyses. The impulse response functions, known as GIRFs (Global Impulse Response Functions), derived from these matrices are particularly attractive in this framework. They offer advantages over Sims's orthogonalized impulse response functions (OIRFs) from 1980, as GIRFs are invariant to the ordering of both variables and countries, as presented in this paper and emphasized by Chudik and Pesaran (2016).

3.2.2 Description and sources of data

We utilized quarterly data on primary commodity market indices and three global macroeconomic variables: output (real GDP), inflation, and real exchange rate. The commodity market dataset contains time series observations on 59 global commodity indices obtained from the IMF primary commodities database (refer to Table 2). The macro data were sourced from the global VAR modeling database[9], originally compiled by Dées et al. (2007) and extended by Mohaddes and Raissi (2020)[10]. This dataset encompasses 33 countries (as shown in Table 1), which collectively account for over 90% of the global GDP. Due to data limitations[11], our analysis was conducted for the period ranging from 1990Q1 to 2019Q4. To focus on regional effects and shocks, we grouped the countries in the GVAR model into specific regions (refer to Table 1). In the VARX* model, the euro area is treated as a single region and aggregated using GDP-weighted averages of the country-specific variables, including real GDP, inflation, and real exchange rate. Table 2 provides an overview of the primary commodities based on the IMF primary commodity groupings. For consistency, all observations in the original dataset were transformed into logarithmic values. For a more detailed summary of these transformed series, please refer to Appendix A.1–A.3.

To address the issue of multicollinearity in LASSO estimation and avoid erroneous identification of relevant commodities in regression, we initiated our empirical analysis by examining the price correlations among different

[9] Available from https://sites.google.com/site/gvarmodelling/data, original version from 1979Q1–2013Q1.
[10] Available from https://www.mohaddes.org/gvar, the updated version from 2013Q2–2019Q4. See Mohaddes and Raissi (2020) for a detailed description and construction of the macro variable data, sources, and related transformations.
[11] Since there was incomplete data for certain countries, such as in the case of the euro area, only 8 out of the original 11 European countries that joined the Eurozone were included in the analysis. These 8 countries are treated as a single economic region in the model (for further reference, see Dees, di Mauro, Pesaran, and Smith, 2007). As for Africa and the Middle East, data was only available for South Africa and Saudi Arabia.

commodity sectors[12]. Given the strong correlation typically observed in global energy prices, especially in the oil and gas sectors, we anticipated finding high price correlations in these markets. Analysis of our data confirms that energy price series, including EU and US natural gas prices, as well as various oil price series such as Brent, Dubai, and WTI, exhibit significant correlation. For instance, static correlations between the US and EU natural gas prices and WTI crude oil prices are 0.91 and 0.90, respectively (shown in Table 3). Multicollinearity in the energy market sectors is visualized in Figure 1. The upper panels A and B of Figure 1 illustrate collinearity in price and return movements within the crude oil market (Brent, Dubai, WTI). Similar patterns can be observed in the lower panels C and D for the natural gas market (US and EU).

Table 1. Countries and regions in the GVAR model

	Other developed countries	Emerging economies excl. China	
USA	Australia	Africa	Asia
UK	Canada	South Africa	Korea
China	Japan		India
	Norway	Middle East	Indonesia
Euro Area	New Zealand	Saudi Arabia	Malaysia
Austria	Singapore		Philippines
Belgium	Sweden	Latin America	Thailand
Finland	Switzerland	Argentina	
France		Brazil	
Germany	Other European countries	Chile	
Italy	Turkey	Mexico	
Netherlands		Peru	
Spain			

[12] The static price correlations in the other primary commodity sectors/categories (i.e., agricultural products, precious and base metals) range from 0.08 to 0.69, which is sufficiently low for all of them to be considered individually in further analyses. We do not report the results here, but they are available upon request.

Table 2. Primary commodities in groups

Vegetable oils	Cereals	Meats and sea food	Beverages	Raw materials	Others
Rapeseed oil	Wheat	Beef	Coffee	Soft Sawnwood	Groundnuts
Olive oil	Rice	Pork meat	Tea, Kenyan	Hard Sawnwood	Corn
Palm oil	Barley	Poultry	Cocoa	Soft Logs	Fertilizer
Sunflower oil	Sorghum	Lamb		Hard Logs	Orange
Soybeans oil	Oats	Shrimp		Cotton	Sugar
Soybeans		Fish		Rubber	Timber
Soybean meal				Softwood	Wool
				Hardwood	Bananas
Precious metals	Base metals	Energy			Potassium Fertilizer
Gold	Lead	EU natural gas			D. phosphate
Silver	Copper	US natural gas			Tomato
Palladium	Iron Ore	Brent crude oil			
Platinum	Nickel	Dubai crude oil			
	Aluminum	WTI crude oil			
	Zinc	Coal			
	Tin				
	Uranium				
	Cobalt				

Source; IMF primary commodity database, (2021)

Table 3. Static price correlations in energy markets

	US natural gas	EU natural gas	Brent crude oil	Dubai crude oil	WTI crude oil
US natural gas	1				
EU natural gas	0.8212	1			
Brent crude oil	0.9423	0.9228	1		
Dubai crude oil	0.9222	0.9319	0.9982	1	
WTI crude oil	0.9144	0.9015	0.9969	0.9944	1

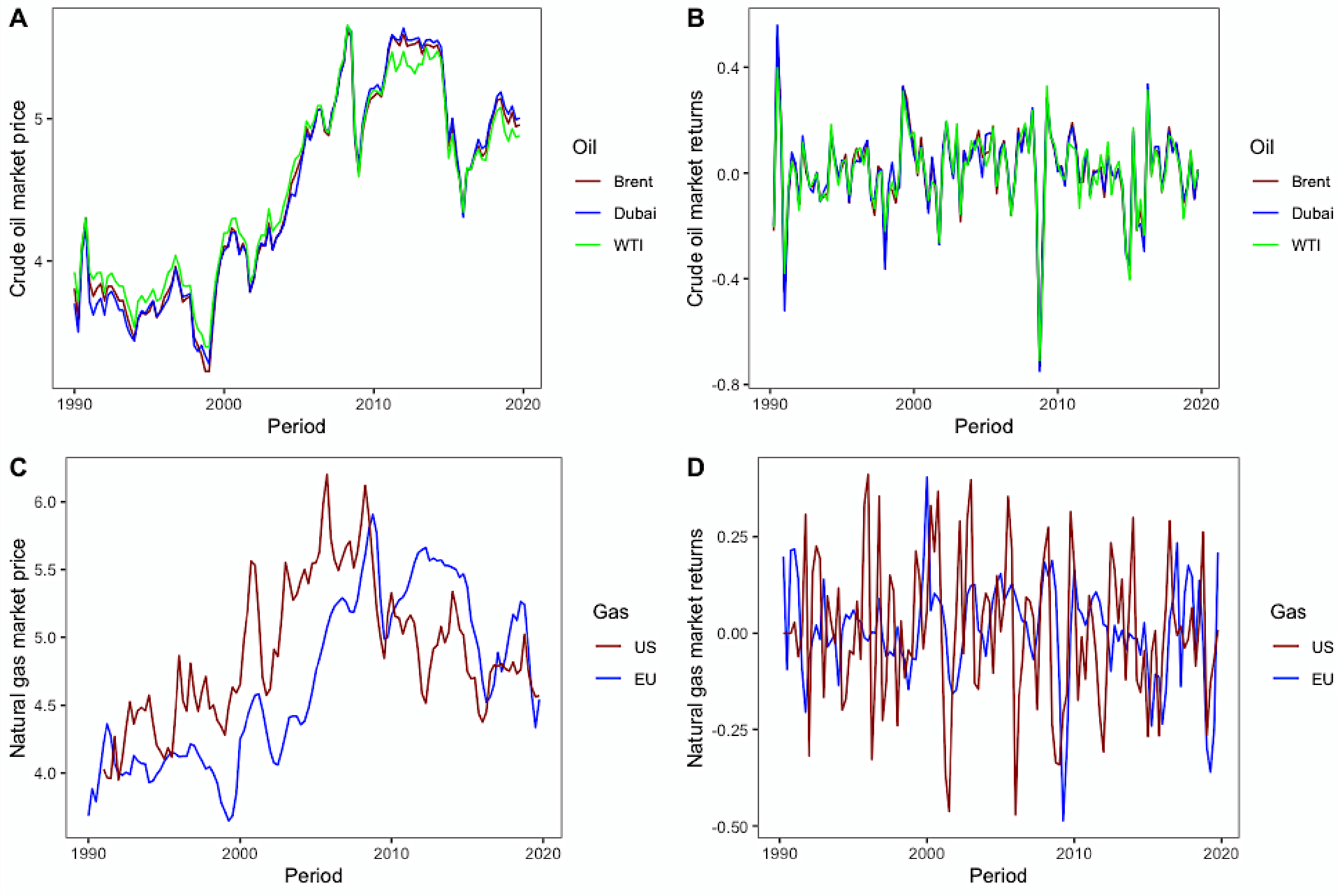

Figure 1. The energy markets' price development: crude oil market price and returns (upper panels A and B), natural gas market price and returns (lower panels C and D).

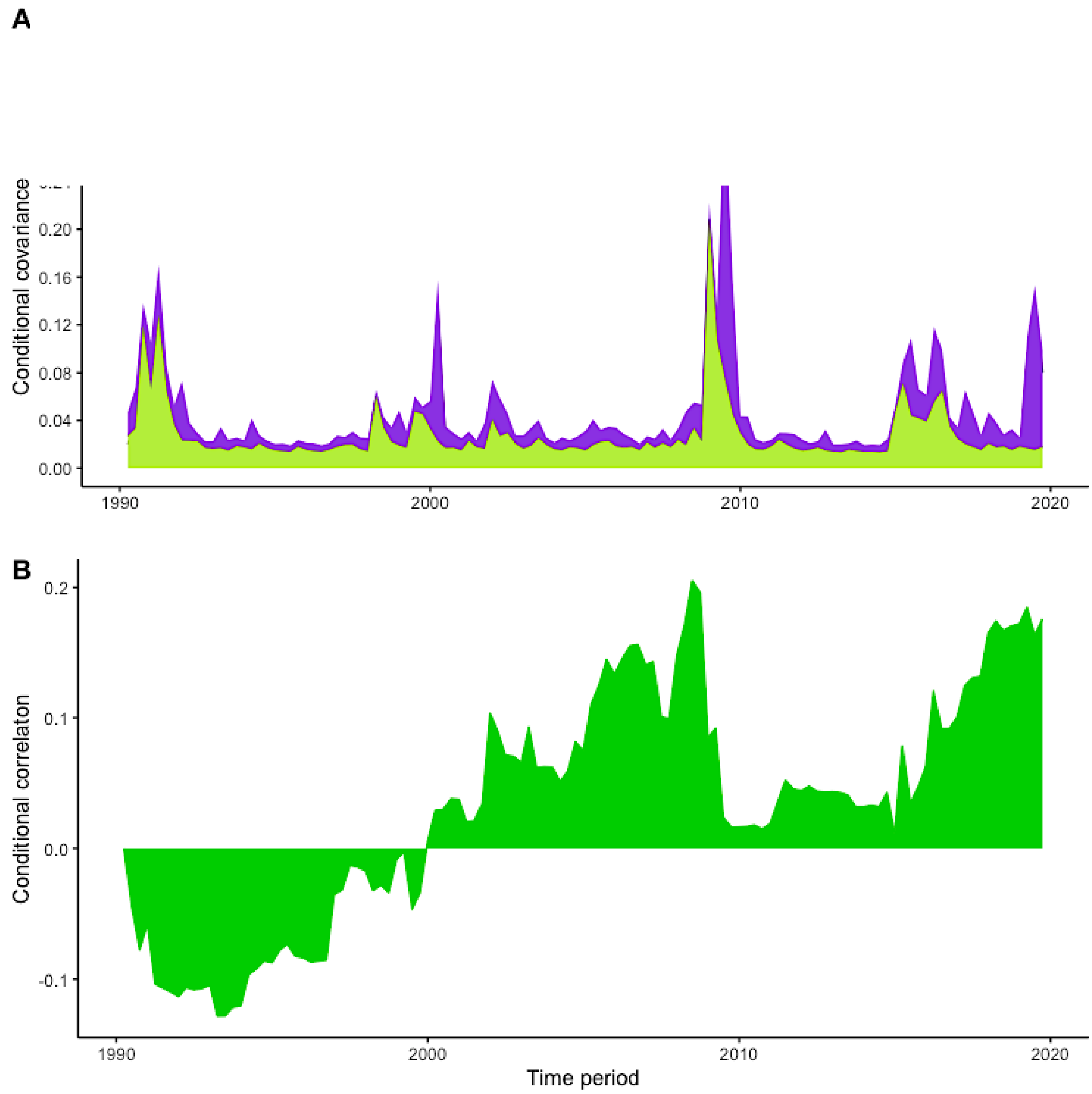

Figure 2. The conditional covariance (A) and correlations (B) between the US natural gas and WTI crude oil price changes

Note: Authors' estimation based on a DCC-GARCH (1,1)- model for log changes in prices.

In order to gain a better understanding of the energy market price dependencies, the analysis was expanded to include the second moments for returns in the oil and natural gas markets. This analysis showed that the volatilities in these two markets are quite similar, with US natural gas shocks appearing to dominate over time (refer to Fig. 2 panel A). Similar to Batten et al. (2017), the dynamic correlations between returns are not stable but rather vary over time[13] (refer to

[13] We utilized a multivariate DCC-MGARCH (1,1) model to dynamically assess the co-movement of the first and second moments within the oil and natural gas markets. While the detailed methodology and equations employed in this analysis are not provided within this document, interested readers can find a comprehensive explanation of the estimation process and derivation of the DCC-MGARCH model in Engle (2002). If you would like more specific information regarding the estimation results based on our particular dataset, please don't hesitate to request additional details.

Fig. 2 panel B). It is also worth noting that the dynamic co-movement between the US natural gas and WTI crude oil markets is time-varying, but the correlation trend has remained relatively stable since the year 2000. Due to the high price co-movement and the similar variance development, it is reasonable to use WTI crude market data to understand the effects of natural gas and other crude oil markets in further estimations. This choice helps mitigate the issue of multicollinearity in the LASSO regressions. Therefore, at this stage, we employed the LASSO model using a set of 55 individual commodity return series.

3.3 Discussion of empirical results

3.3.1 Unit root tests

Our empirical analyses further proceeded with the implementation of unit root tests to determine the level of integration exhibited by the individual data series. This is crucial for both main estimation stages, especially in the context of GVAR modeling. The results obtained from the Augmented Dickey-Fuller (ADF) unit root test, which utilizes the Akaike Information Criterion (AIC) lag selection criterion to determine the optimal lag length for the test equation, are presented in Table 4.

Panel A presents statistical data for both domestic and foreign macro variables, presented in levels and first differences. Panel B, on the other hand, provides the corresponding estimates for the four most globally significant commodity market variables, specifically the commodity price levels and changes identified using LASSO selection. The estimates provided in Table 4 clearly indicate that, except for domestic inflation, the majority of variables can be considered to possess an I(1) nature, meaning they follow unit root processes in levels. In most instances, the null hypothesis of a unit root process (indicating non-stationarity) cannot be rejected for the level observations, but it is rejected for the first differences. This rejection provides statistical support for the estimation of an error correction version of the GVAR model, as represented by Equation 5.

3.3.2 LASSO estimation results

In many cases, machine learning algorithms are employed in empirical analysis to utilize all available information and predict the response variable, without assuming causality for any particular predictor. Therefore, in the initial stage of our analysis, our focus is solely on identifying the relevant commodities associated with macroeconomic changes. The structural impact analysis will commence from Section 3.3, where we will examine the macroeconomic responses to the structural shocks originating from a set of the most significant commodity markets, employing a purely statistical perspective.

Table 4. Augmented Dickey–Fuller (ADF) unit root test statistics

	Domestic variables					Foreign variables				
Panel A	*y*	*△y*	*xr*	*△xr*	*nfa*	*y**	*△y**	*xr**	*△xr**	*nfa**
Argentina	-1.80	-3.98	-2.31	-5.23	-8.01	-0.86	-5.52	-1.72	-7.05	-7.11
Australia	-0.80	-3.89	-2.07	-7.47	-8.62	-1.12	-5.28	-1.68	-7.58	-7.18
Brazil	-1.65	-5.63	-2.02	-6.74	-6.88	-1.21	-4.70	-1.48	-5.29	-7.51
Canada	-1.39	-5.20	-1.62	-7.20	-10.22	-1.58	-5.20	-1.47	-8.21	-7.51
China	-0.77	-3.06	-2.75	-7.58	-5.93	-2.36	-5.70	-1.93	-7.26	-8.03
Chile	-2.43	-5.96	-1.88	-7.35	-7.38	-0.76	-5.28	-1.71	-7.46	-5.79
Euro area	-1.93	-4.97	-1.86	-7.77	-7.28	-1.60	-5.11	-1.50	-8.29	-7.40
India	-2.91	-5.01	-3.46	-6.96	-9.58	-1.30	-5.19	-1.76	-7.31	-9.77
Indonesia	-1.72	-5.87	-2.49	-8.00	-7.06	-1.65	-5.22	-1.85	-7.22	-10.50
Japan	-3.84	-6.78	-2.80	-5.17	-9.90	-0.80	-5.22	-1.91	-6.97	-8.72
Korea	-2.29	-5.15	-3.18	-8.06	-7.99	-0.69	-5.16	-1.69	-7.35	-8.87
Malaysia	-3.30	-5.74	-2.33	-6.76	-8.82	-1.62	-5.23	-1.84	-6.97	-7.04
Mexico	-3.07	-6.48	-2.69	-5.59	-13.04	-1.53	-4.84	-1.76	-7.33	-7.45
Norway	-1.96	-6.10	-1.89	-7.58	-7.93	-1.92	-4.48	-1.80	-8.22	-7.40
New Zealand	-2.03	-4.04	-2.37	-6.85	-7.93	-0.62	-5.70	-1.88	-7.16	-7.64
Peru	-1.38	-4.17	-2.11	-7.03	-14.93	-0.81	-4.72	-1.69	-7.36	-7.27
Philip-pines	-2.38	-3.81	-1.91	-5.79	-8.80	-1.97	-5.28	-1.93	-7.24	-7.49
South Africa	-1.22	-4.45	-2.33	-7.32	-8.47	-1.17	-5.20	-1.63	-7.91	-10.75
Saudi Arabia	-1.43	-3.74	-1.27	-5.46	-7.88	-1.51	-5.49	-1.68	-7.55	-10.73
Singapore	-1.36	-5.71	-1.63	-6.14	-7.06	-2.72	-5.57	-2.08	-6.56	-7.44
Sweden	-4.02	-5.84	-2.52	-7.56	-7.60	-1.42	-5.02	-1.74	-7.91	-11.65
Switzer-land	-3.60	-4.86	-2.16	-8.54	-8.24	-1.81	-4.88	-1.76	-7.88	-11.87
Thailand	-2.86	-7.05	-2.18	-6.98	-8.02	-1.85	-5.54	-1.86	-7.27	-9.84
Turkey	-2.85	-7.05	-0.48	-6.59	-7.84	-1.57	-5.15	-1.76	-7.83	-10.42
UK	-1.56	-4.69	-1.85	-9.27	-8.52	-1.68	-5.12	-1.71	-7.65	-11.71
USA	-1.90	-4.62			-10.30	-1.13	-5.49	-1.66	-7.76	-6.35
Panel B	cop-per	△cop per	oil		△oil	gold	△gol d	lead	△lead	
Global variables	-2.14	-7.73	-1.52		-6.96	-1.54	-6.44	-2.99	-6.23	

Notes: The ADF test statistics presented are based on univariate AR(p) models in the levels with the lags *p* chosen according to the modified AIC, and a maximum lag order of 8. The regressions for all variables in the levels include an intercept and a linear trend. The critical value for a rejection in a test procedure including a trend series to the test equation is −3.46 at a 5% significance level. For the notations, *y* denotes real output, *xr* is real exchange rate, and *nfa* refers to inflation (i.e., log change in the CPI index).

Without making any prior assumptions in our machine learning estimation, the LASSO regression revealed that out of the 55 commodity price changes analyzed, only four - crude oil, copper, gold, and lead prices - emerged as relevant predictors for global macroeconomic performance. These findings hold true even after accounting for multicollinearity issues and conducting robustness checks. To validate these results, we conducted principal component analysis (PCA)[14] and factor analyses as robustness checks. The results from PCA and factor analysis support the notion that these commodities (crude oil, copper, gold, and lead) are of utmost importance when it comes to global macroeconomic performance. These findings are consistent with various previous studies that have also identified crude oil, copper, and gold market price developments as indicators of global economic performance (Bildirici and Gokmenoglu, 2020; Stuermer, 2018; Arora and Cai, 2014; Jaunky, 2013; Boschi and Girardi, 2011).

The results reported in Table 5 indicate that changes in copper and crude oil prices are the most significant commodities for assessing global output (real GDP) changes. Our empirical estimates from this stage of the analysis suggest that when prices in these markets increase, there is a general improvement in macroeconomic performance. These estimates further support the notion that positive developments in the copper market price, often referred to as 'Dr Copper,' serve as significant indicators of global economic health, corroborating previous findings such as those of Stuermer (2018).

Our estimation results consistently demonstrate that the crude oil market has the utmost significance among primary commodity markets when it comes to the global transmission of inflationary pressures. This finding aligns with several recent studies that have come to the same conclusion (Fasanya and Awodimila, 2020; Bettendorf, 2017; Chudik and Fidora, 2012; Kilian, 2009). When examining the economic impact, Table 5 illustrates that changes in copper and oil market prices, as energy market commodities, have similar effects on real economic activity across different countries. In most cases, the coefficient ranges between 0.1 and 0.2, rounded to two decimal points. However, it is worth noting that the primary driver of aggregate inflation appears to be changes in crude oil market prices, and this effect seems to be consistent across all countries.

Furthermore, a comparison at the country level indicates that macroeconomic indicators in European countries are particularly vulnerable to commodity market price risks.

The results presented in Table 5 emphasize the significant impact of gold and lead market price changes on the development of the real exchange rate. Notably, an increase in gold prices is strongly associated with a depreciation of the exchange rate. This outcome is not surprising, considering the gold market's sensitivity to global economic fluctuations, making its price a reliable indicator

[14] We do not report the results from the PCA, and factor analyses here, though they are available upon request.

of global economic well-being[15]. Our findings align with previous studies (e.g., Capie et al., 2005), which have consistently shown a negative relationship between gold price movements and dominant currencies like the US dollar. Moreover, the research of Giannellis and Koukouritakis (2019) and Wang and Lee (2016), among others, provides support for the idea that the gold market offers protection against currency risks. Table 5 also reveals the diverse effects of various commodity markets on the real exchange rates of different countries. In the majority of cases, an increase in commodity market prices correlates with a depreciation in the domestic real exchange rate, implying a decline in the currency's value.

[15] Gold is widely acknowledged as a safe haven asset, making it an attractive component of asset portfolio diversification (Sui, Rengifo, and Court 2021; Behmiri et al. 2021). During periods of economic turbulence, investors often seek alternative assets to protect their holdings, particularly in foreign currencies. The reason behind this phenomenon is that gold is recognized for its ability to provide a hedge against the inherent risks present in stock and currency markets (recent evidence can be found in Wang and Lee 2021).

Table 5. Estimates for the effects on macroeconomy from the LASSO-selected commodity market returns – 1990Q1-2019Q4

	Output (real GDP)		Inflation	Real exchange rate	
Country	Copper	Oil	Oil	Gold	Lead
Argentina		0.03 (0.01) ***			
Australia			0.01 (0.00) ***	-0.24 (0.04) ***	0.18 (0.04) ***
Austria	0.01 (0.00) **	0.02 (0.01) *	0.01 (0.00) ***	-0.17 (0.05) ***	
Belgium	0.01 (0.00) **	0.01 (0.00) *	0.01 (0.00) ***	-0.15 (0.05) ***	-0.05 (0.02) **
Brazil	0.01 (0.01)	0.04 (0.01) ***		-0.25 (0.08) ***	-0.23 (0.06) ***
Canada			0.01 (0.00) **	-0.15 (0.05) ***	-0.10 (0.03) ***
China	0.00 (0.01)				
Chile	0.02 (0.01) **			-0.20 (0.07) ***	-0.11 (0.04) ***
Finland	0.02 (0.01) **	0.02 (0.01) **	0.02 (0.01) **	-0.16 (0.05) ***	-0.09 (0.04) ***
France	0.01 (0.00) **	0.01 (0.00) **	0.01 (0.0) ***	-0.16 (0.04) ***	
Germany	0.01 (0.00) *		0.02 (0.00) ***	-0.13 (0.05) **	-0.06 (0.03) **
India	0.02 (0.01) *			-0.13 (0.06) **	-0.09 (0.02) ***
Indonesia	0.01 (0.00) *	0.01 (0.02)		-0.41 (0.26) ***	
Italy	0.02 (0.00) **	0.02 (0.01) *	0.01 (0.00) **	-0.15 (0.05) ***	-0.08 (0.03) ***
Japan	0.02 (0.00) ***			-0.38 (0.06) ***	0.09 (0.04) **
Korea	0.02 (0.01) *	0.02 (0.01) *		-0.20 (0.07) **	-0.14 (0.04) ***
Malaysia		0.02 (0.00) **	0.02 (0.00) **	-0.20 (0.06) ***	
Mexico	0.02 (0.01) *		-0.01 (0.01)		
Netherlands				-0.14 (0.05) **	-0.06 (0.03) **
Norway	0.02 (0.01) **	0.02 (0.01) **	0.01 (0.00) **	-0.19 (0.06) ***	
New Zealand		0.01 (0.00) ***		-0.23 (0.07) ***	-0.17 (0.04) ***
Peru	0.02 (0.01) *				
Philippines	0.02 (0.01) *	0.01 (0.00) *		-0.10 (0.05) *	-0.07 (0.03) **
South Africa	0.01 (0.01)	0.01 (0.00) **	0.00 (0.01)	0.41 (0.15) ***	-0.20 (0.10) **
Saudi Arabia	-0.00 (0.01)	0.01 (0.00) *		-0.04 (0.01) ***	
Singapore	0.04 (0.01) ***		0.01 (0.00) *	-0.17 (0.04) ***	-0.015 (0.02)
Spain			0.01 (0.00) ***	-0.11 (0.05) **	

Country	Output (real GDP)		Inflation	Real exchange rate	
	Copper	Oil	Oil	Gold	Lead
Sweden	0.02 (0.01) *	0.01 (0.00) *		-0.14 (0.04) ***	-0.09 (0.03) ***
Switzerland	0.02 (0.01) **	0.01 (0.00) *	0.01 (0.00) **	-0.14 (0.05) ***	
Thailand	0.02 (0.00) ***		0.02 (0.00) ***	-0.35 (0.06) ***	-0.06 (0.02) ***
Turkey	0.01 (0.00) **	0.02 (0.01) *			
United Kingdom			0.01 (0.01)		0.02 (0.07)
USA			0.02 (0.00) ***		0.04 (0.05)
Mean	0.02	0.02	0.01	-0.16	-0.06
Maximum	0.04	0.04	0.02	0.41	0.18
Minimum	-0.00	0.01	-0.01	-0.41	-0.23
Standard deviation	0.01	0.01	0.01	0.14	0.10
Number (#) of significant effects/total # of countries	20/33	17/33	15/33	26/33	17/33

Notes: This table presents the commodities selected by the LASSO method (4 out of the 55 commodity indices in row 2) that have a significant impact (in at least 50% of all analyzed cases) on global macroeconomic variables such as real GDP, inflation, and real exchange rate. The model is estimated using Ordinary Least Squares (OLS) with robust standard errors in parentheses. Statistical significance is denoted by *, **, and *** for the 10%, 5%, and 1% levels, respectively. The reported estimates are rounded to two decimal points. For example, in the case of Argentina, the estimate for crude oil is 0.0313, rounded to 0.03. In Belgium, the estimates for copper and crude oil are 0.0131 and 0.0093, rounded to 0.01 and 0.01 respectively. In Finland, the estimates for copper and crude oil are 0.022 and 0.024, rounded to 0.02 and 0.02 respectively. Empty cells indicate that LASSO omitted statistically insignificant estimates.

Based on our analysis, one of the important commodities we focused on was lead. Our research revealed novel findings regarding the role of lead market prices, which bear similarity to the impact observed in the gold market. It is evident that lead market prices significantly influence the real exchange rates of nearly every individual country. Digging deeper into the economic significance of the lead market, we found that lead, like other base metals such as zinc, silver, and copper, is extracted from galena and sourced from ore. From a global perspective, over 86% of refined lead and lead-related products are utilized in various industries including automobile manufacturing, batteries, pigments, and ammunition (U.S. Geological Survey, 2019). China, Australia, and the USA are the primary producers of lead, followed by Peru, Canada, Mexico, Sweden, and South Africa (U.S. Geological Survey, 2019). It is important to note that all these countries were included in our study to ensure comprehensive analysis.

The prominent role of lead in international trade may explain why the development of lead market prices is considered a crucial commodity for analyzing exchange rate movements using the LASSO method. According to Table 5, the impact of lead market price development on economies varies across countries. For instance, when global lead market prices increase, countries like Australia and Japan experience a significant appreciation of their real exchange rates, while others witness a depreciation. Recently, lead prices have surged to their highest level since 2018 amid the post-Covid-19 global economic recovery and the energy crisis. This increase is mainly attributed to the anticipation of supply disruptions in Europe and the growing global demand for traditional lead-acid car batteries from China, the USA, and Europe (World Bank Group, 2021). The World Bank's commodity market outlook for 2021 projected that lead prices would remain stable at pre-pandemic levels in both the medium and long term (World Bank Group, 2021). Nonetheless, this outlook might have changed due to the onset of the war in Ukraine in early 2022.

In order to conduct further robustness checks, we excluded the data from the global economic and financial crises of 2008-2009. This data spanned from 2007Q1 to 2009Q4. Subsequently, we performed LASSO estimation on two sub-samples referred to as 'pre-crisis' (covering the period from 1990Q1 to 2006Q4) and 'post-crisis' (covering the period from 2010Q1 to 2019Q4). The results of these estimations are presented in Tables A.1 and A.2 in the Appendix. Overall, the set of four significant commodities identified in the full sample estimation remains consistent. Notably, we observed a significant increase in the overall importance of these commodities to their respective macro variables during the post-crisis period (see Table A.2 in the Appendix).

Testing for weak exogeneity of foreign-specific and global variables in the GVAR model

In the second stage of our estimation process, we begin by examining the weak exogeneity of the foreign and global variables in our estimated GVAR systems. The weak exogeneity assumption is critical in the estimation process of the global VAR approach. To test the joint significance of the foreign and global variables in each country-level regression equation, we estimate an error correction model using the data. Following the approach used in studies by Pesaran et al. (2004), Boschi and Girardi (2011), and Gutierrez and Piras (2013), we first group the foreign and global variables together in the vector Δy_{it}^{*}. Subsequently, we construct the regression model based on equation 7.

$$\Delta y_{it,l}^{*} = \mu_{il} + \sum_{j=1}^{r_i} \gamma_{ij,l}\, ECM_{i,t-1}^{j} + \sum_{k=1}^{p_i} \varphi_{ik,l} \Delta \mathbf{y}_{i,t-k}^{j} + \sum_{m=1}^{q_i} \theta_{im,l} \Delta \tilde{\mathbf{y}}_{i,t-m}^{*} + \varepsilon_{it,l,} \quad (7)$$

In the given equation, the ECM term, denoted as $ECM_{i,t-1}^{j}, j = 1, 2, .., r_i$ corresponds to the estimated error correction term for each macro variable (j) of each country. The value of r_i represents the number of cointegration relations found for that particular macro variable. The differential notation (Δ) represents the first difference operation, so $\Delta \mathbf{y}_{i,t-k}^{j}$ implies the domestic macro variables expressed as differences over the lag period of k. Similarly, $\Delta \tilde{\mathbf{y}}_{i,t-m}^{*}$ represents the foreign and global variables expressed as differences over the lag period of m. Furthermore, $k = 1, \dots, p_i$ and $m = 1, \dots, q_i$, where p_i and q_i are the maximum lag orders of the domestic, foreign and global variables for each of the i^{th} country models[16], respectively. The test for weak exogeneity is an F-test for the joint significance of the hypothesis $\gamma_{ij} = 0, j = 1, 2, .., r_i$ at a 5% significance level of the i^{th} country model using the above regression representation. In particular, the test assumes that both the foreign-specific and global variables enter the model as weakly exogenous. We thus verify the null hypothesis of weak exogeneity for both the foreign-specific and global variables against the alternative hypothesis of no weak exogeneity for both the foreign-specific and global variables.

The results presented in Table 6 indicate that out of the 130 cases analyzed, only 10 cases show a rejection of the null hypothesis regarding the weak exogeneity assumption. This favorable outcome strengthens the support for the weak exogeneity hypothesis within our sample. However, it is important to note that the assumption of weak exogeneity for global variables is challenged in several countries. This implies that, from a purely statistical perspective, the changes in prices observed in these markets cannot be considered weakly exogenous in relation to the macroeconomic developments of those countries.

For instance, the analysis reveals that the changes in copper prices cannot be considered weakly exogenous for countries such as Indonesia, Norway, the Philippines, and Sweden. Similarly, the exogeneity of crude oil price changes is rejected for Malaysia. On the other hand, the exogeneity of gold price changes is only rejected for Saudi Arabia, while the exogeneity of lead price changes is rejected for both Sweden and the USA.

16 The lag orders of the weakly exogenous variables and the number of cointegrating relationships for country specific models are reported in Appendix A.4.

Table 6. F-statistics for testing the weak exogeneity of the country-specific foreign and global variables

Country/ region	F test	95% F-Stat. Critical value	Foreign variables: Output	Foreign variables: Inflation	Global variables: Copper	Global variables: Oil	Global variables: Gold	Global variables: Lead
Argentina	F(2,95)	3.09	0.44	1.09	2.45	1.41	1.38	0.06
Australia	F(3,99)	2.70	0.08	1.31	1.12	0.83	2.42	0.51
Brazil	F(2,97)	3.09	0.16	0.86	1.71	0.05	0.37	0.93
Canada	F(3,99)	2.70	0.75	2.47	2.15	1.44	0.86	1.56
China	F(2,97)	3.09	0.17	0.31	0.46	0.38	0.49	0.02
Chile	F(2,95)	3.09	1.64	0.37	0.68	0.27	0.38	1.38
Euro area	F(1,101)	3.94	0.45	0.02	0.41	1.83	1.12	1.19
India	F(2,100)	3.09	0.98	1.29	0.10	0.56	0.56	0.33
Indonesia	F(3,101)	2.69	0.62	0.55	2.72#	1.05	0.45	0.42
Japan	F(2,100)	3.09	2.29	1.37	1.26	0.31	0.45	3.08
Korea	F(3,99)	2.70	3.62#	0.71	0.72	0.41	0.91	1.01
Malaysia	F(2,101)	3.09	2.23	2.68	0.57	3.23#	0.01	1.28
Mexico	F(2,102)	3.09	1.34	0.29	0.14	0.52	0.33	0.61
Norway	F(3,99)	2.70	1.06	1.82	3.21#	1.51	1.30	1.44
New Zealand	F(3,99)	2.70	2.28	0.78	0.94	0.58	0.91	1.14
Peru	F(2,102)	3.09	1.83	0.75	0.42	0.05	0.61	0.63
Philippines	F(3,100)	2.70	0.49	2.20	2.96#	1.42	0.72	0.91
South Africa	F(2,100)	3.09	0.78	0.42	2.63	1.07	1.53	1.28
Saudi Arabia	F(1,104)	3.93	0.01	0.06	0.81	1.41	5.38#	0.36
Singapore	F(1,102)	3.93	1.07	0.85	0.20	0.41	1.56	0.37
Sweden	F(2,100)	3.09	0.11	1.62	4.41#	1.33	0.50	8.22#
Switzerland	F(3,99)	2.70	3.56#	0.97	1.25	0.71	0.09	0.90
Thailand	F(2,101)	3.09	0.03	0.48	1.71	0.14	2.88	0.35
Turkey	F(1,103)	3.93	0.08	0.96	0.60	0.39	0.93	1.81
UK	F(2,100)	3.09	1.49	1.35	2.06	2.52	1.06	0.44
USA	F(2,103)	3.08	1.04	1.87	2.90	1.50	0.51	4.38#

Notes: This table presents the F-Statistics for testing the weak exogeneity of the country-specific foreign and global variables in our GVAR model. The # denotes the rejection of the null hypothesis of the weak exogeneity assumption at the 5% significance risk level.

3.3.3 Impact elasticities at the country level

In this study, we utilize error correction model versions of the VARX* representations to analyze the contemporaneous impacts of foreign variables on domestic counterparts. We also assume the weak exogeneity of the foreign variables. The estimation procedure in the GVAR framework maintains consistency, ensuring that the variables of each model interact in the long run. This analysis is particularly valuable on a global scale, as it allows us to investigate the feedback effects from foreign variables (Pesaran et al., 2004; Galesi and Lombardi, 2009). Specifically, we focus on impact elasticities, as discussed in Galesi and Lombardi (2009). These elasticities measure the immediate variation of a domestic variable resulting from a 1% change in the corresponding foreign variables.

For instance, we examine the impact of a 1% increase in foreign-specific inflation on domestic inflation, based on the research conducted by Pesaran et al. (2004). This analysis is crucial in order to evaluate the spillover effects originating from foreign variables. Table 7 presents the results, showing that the estimated coefficients are predominantly positive, except for the inflation effects observed in Brazil, Chile, and Japan. Many of the countries/regions demonstrate statistically significant impact elasticities, indicating a notable influence of foreign variables. Additionally, all countries/regions exhibit statistically significant exchange rate elasticities. The statistical significance of the effects of foreign variables on domestic counterparts is particularly high for both output and inflation. For output, the estimated coefficients range from 0 to 2, with Argentina showing the lowest value (0.15) and Turkey demonstrating the highest (2.01). Notably, the impact elasticity is statistically significant and exceeds one for Turkey (2.01), Sweden (1.247), Singapore (1.32), and Malaysia (1.12). This implies that the domestic output reacts more strongly to an increase in the output of major trading partners.

The estimated impact elasticity with respect to inflation has a range between -3 and 1. For example, the inflation effects is significant for Argentina (1.08) and India (1.02), indicating an overreaction of domestic inflation relative to the increase in inflation of their main trading partners. On the other hand, statistically non-significant estimates suggest that the inflation dynamics would be independent of foreign countries' inflationary pressure. Furthermore, a statistically significant impact elasticity greater than one is observed for the real exchange rate in several countries such as Argentina (1.77), Canada (1.21), Euro area (1.18), Korea (1.05), Malaysia (1.01), Norway (1.08), Sweden (1.23), and Thailand (1.38). This indicates an overreaction or influence of an increase in the real exchange rate of major trading partners on the domestic real exchange rate. Overall, these findings align with the research conducted by Galesi and Lombardi (2009), which demonstrates that foreign variables significantly impact domestic macroeconomic performance in most countries.

Table 7. Contemporaneous effects of foreign variables on domestic counterparts

Country/region	Output	Inflation	Real exchange rate
Argentina	0.149 (0.44)	1.088* (3.49)	1.768* (3.26)
Australia	0.177* (2.32)	0.238 (1.28)	0.899* (4.05)
Brazil	0.657* (3.09)	-3.72 (-1.62)	–
Canada	0.520* (5.82)	0.714* (5.25)	1.207* (3.26)
China	0.997* (3.84)	0.243 (0.96)	–
Chile	1.075* (2.59)	-0.212 (-1.31)	0.713* (6.73)
Euro area	0.411* (5.04)	0.285* (4.95)	1.178* (5.06)
India	0.465 (1.35)	1.017* (2.65)	0.173* (0.13)
Indonesia	0.447 (1.80)	1.081 (1.58)	–
Japan	0.633* (3.45)	-0.008 (-0.07)	0.750* (4.29)
Korea	0.203 (1.04)	0.585* (3.77)	1.049* (6.64)
Malaysia	1.115* (5.92)	0.569* (3.06)	1.009* (7.07)
Mexico	0.202 (1.04)	0.540 (1.70)	–
Norway	0.895* (3.35)	0.630* (2.29)	1.085* (5.08)
New Zealand	0.336* (2.43)	0.512* (5.13)	0.604* (5.73)
Peru	0.914* (3.54)	2.982 (1.78)	–
Philippines	0.270 (1.67)	0.628* (2.75)	1.072* (7.76)
South Africa	0.092 (0.84)	0.268 (1.14)	0.767* (8.43)
Saudi Arabia	0.312 (1.37)	0.203* (3.02)	–
Singapore	1.328* (5.15)	0.019 (0.20)	0.992* (6.07)
Sweden	1.247* (6.90)	0.567* (3.08)	1.235* (4.07)
Switzerland	0.219 (1.44)	0.225* (2.52)	0.905* (6.18)
Thailand	0.970* (2.28)	0.571* (3.08)	1.379* (0.18)
Turkey	2.016* (3.15)	0.790 (0.58)	–
UK	0.605* (5.72)	0.369* (3.39)	0.724* (0.06)
USA	0.450* (4.19)	0.267* (4.81)	–

Notes: White's heteroskedastic-robust t-ratios are given in parentheses.

3.3.4 Shock reactions

In this section, we employed GIRFs (Generalized Impulse Response Functions) to analyze the response of global macroeconomic variables to commodity price shocks. We obtained point estimates for the simulation horizon, which covers a period of up to 40 periods or 10 years. This allows us to examine the long-term effects of these shocks. Moreover, we also conducted a comparative analysis to highlight the differences between our findings and those of several other studies that have focused on the same set of commodities as ours. By doing so, we aim to provide a comprehensive understanding of the topic and contribute new insights to the existing literature.

3.3.4.1 Real GDP

Figure 3 depicts the responses of real output to shocks in the copper market price. Both advanced economies (Panel A) and emerging economies (Panel B) tend to experience an improvement in regional real output over an eight-quarter period (equivalent to two years) following a positive copper price shock. The impact of the shock on regional output, ranging from approximately 0.10 to 0.60 basis points, is generally statistically significant throughout the simulation horizon for both advanced and emerging economies (refer to Figure A.2 for detailed individual reactions with confidence bands[17]). These findings are consistent with the previous results reported in Table 5, which also demonstrate positive responses in regional output. Interestingly, while some regions show modest reactions to copper price shocks after two years, China and Africa (represented by South Africa) exhibit more pronounced effects even within the first two years. One possible explanation for China's persistence in reacting to these shocks could be its significant reliance on copper in industrial production. On the other hand, it is not immediately clear why Africa would display such strong reactions, considering that it is neither a major exporter nor importer of copper.

Our findings support and align with previous research. For instance, Stuermer (2018) confirms that shifts in copper prices have a stimulating effect on global real GDP. Similarly, we observe a positive and statistically significant rise in world output following the price shock, consistent with Stuermer's results. This boost typically persit for approximately five years. Furthermore, other studies, namely Wen, Zhao, and Hu (2019) as well as Marañon and Kumral (2020), have also documented a favorable and significant impact of international copper price shocks on key macroeconomic indicators across different regions. These indicators encompass GDP, inflation, and exchange rates.

[17] For comprehensive display of the shocks, please refer to Appendix 3.A, Figures A.2 to A.5. These figures present detailed simulations of Generalized Impulse Response Functions (GIRFs) for global macroeconomic variables. Additionally, we have included 95% confidence bands to provide a measure of uncertainty. These simulations specifically illustrate the individual reactions of the macroeconomic variables to commodity price shocks.

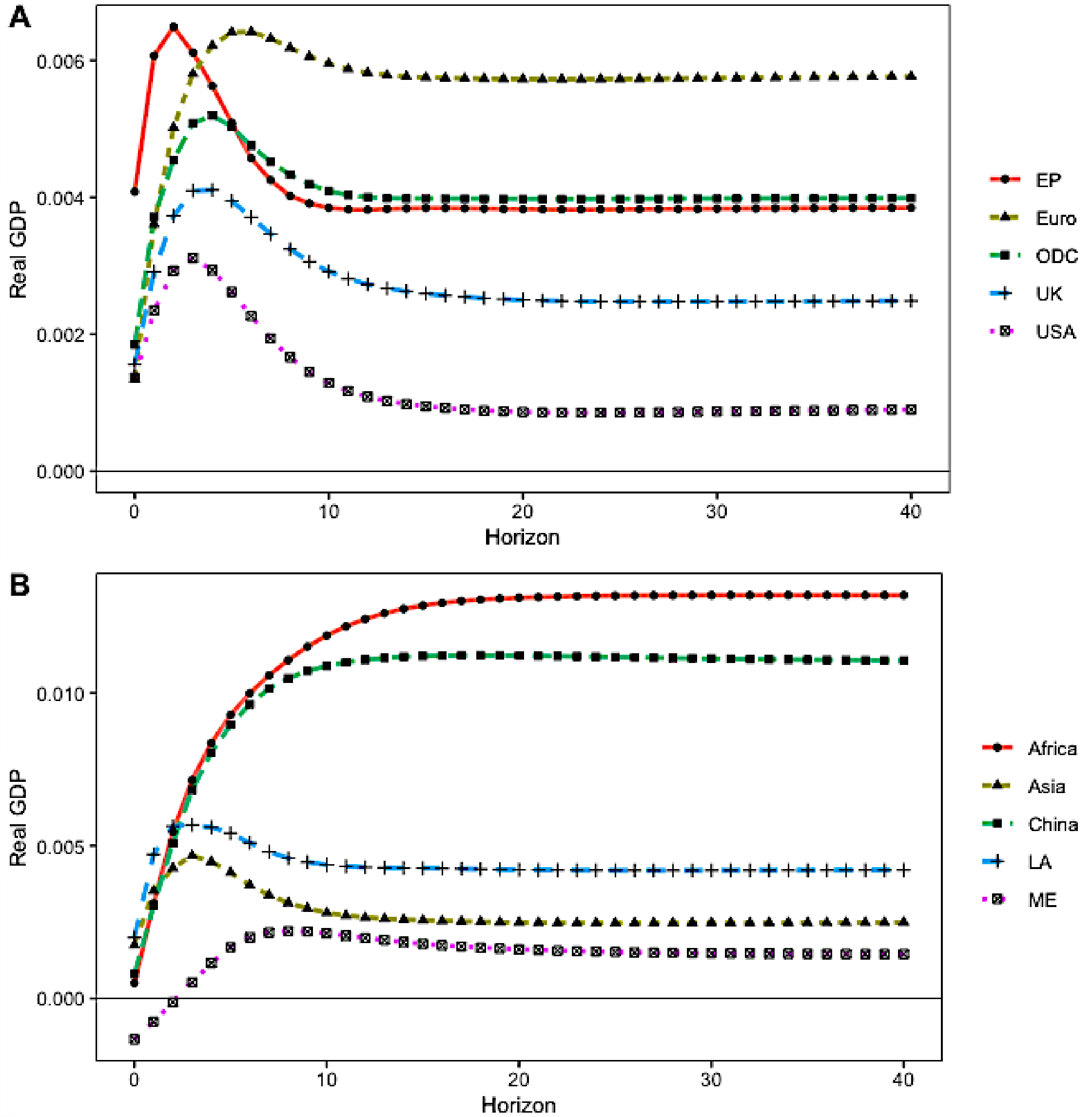

Figure 3. GIRFs of a positive unit (one s.e.) shock to copper price changes for advanced (panel A) and emerging economies (panel B)

Notes: EP denotes other European countries, Euro is Euro area, LA is Latin America, ME is Middle East, and ODC is other developed economies.

Figure 4 presents the impulse response functions (GIRFs) of a positive one standard error shock to changes in crude oil prices on regional output components. On average, this shock leads to an increase in output ranging from 0.10 to 0.50 basis points. For advanced economies (Figure 4, panel A), the effect of the shock on regional output may persist for approximately six quarters before returning to pre-shock levels or fading out completely. However, this pattern is not observed in some emerging economies (Figure 4, panel B). In terms of the oil market price change, the impact of the shock is more pronounced for emerging economies compared to advanced economies. This is consistent with the findings presented in Table 5 and can also be seen in Figure A.3 in Appendix A.

These reactions align with previous research (Boschi and Girardi, 2011) and indicate that regional output is significantly influenced by oil price shocks in both the short and medium terms. On the other hand, Chudik and Fidora (2012) examined the response of regional output to negative oil supply shocks in advanced and emerging economies. Their findings suggest that both types of economies experience a decline in output following a negative oil supply shock. Specifically, emerging economies in Asia and Latin America tend to experience sharper declines in output growth on average.

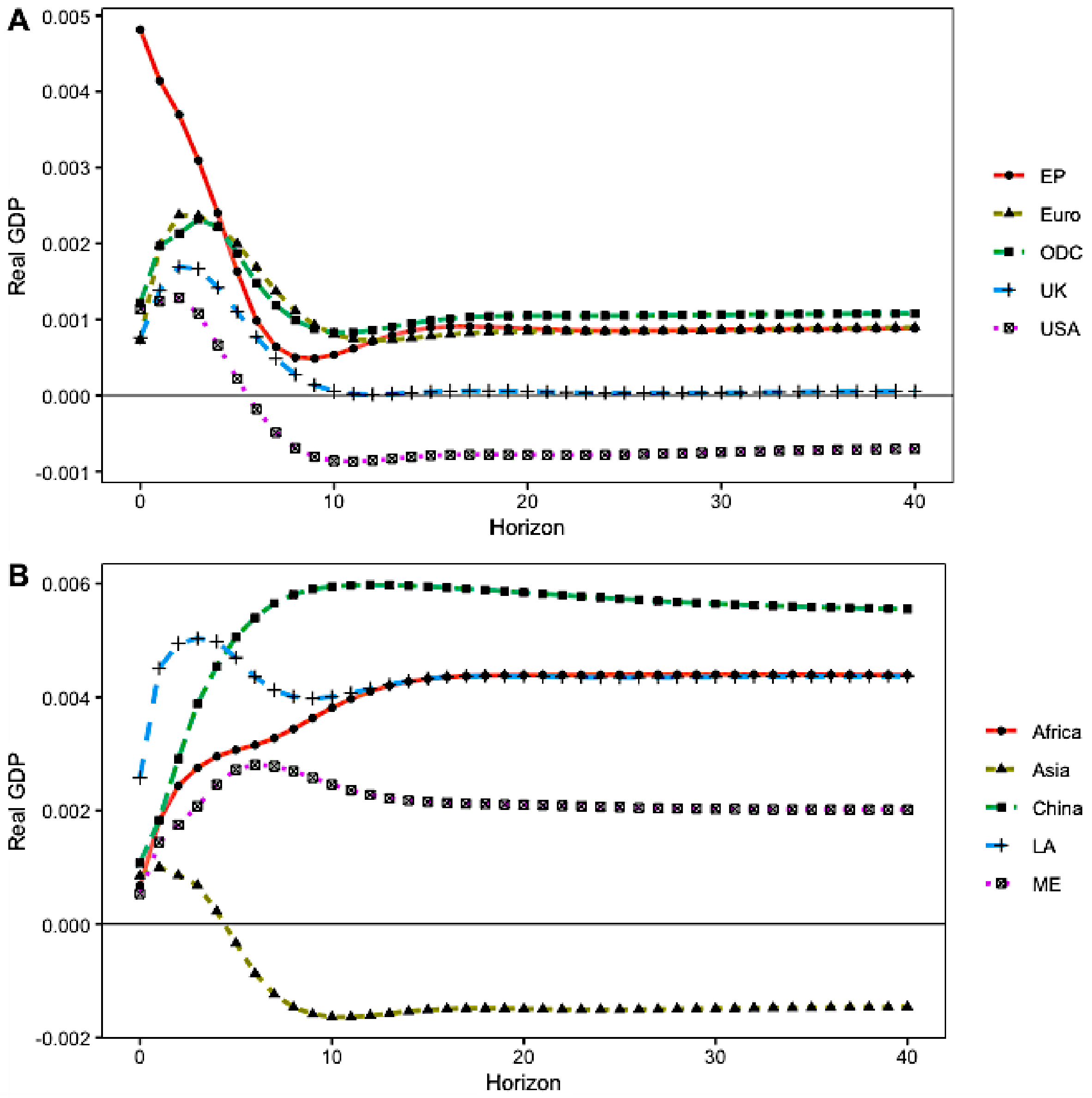

Figure 4. GIRFs of a positive unit (one s.e.) shock to the crude oil price changes for advanced (panel A) and emerging economies (panel B). For notes, see Figure 2.

Real exchange rate

In Figure 5, we can observe the responses of the regional real exchange rate to a positive shock in gold price changes. These responses align with the negative effects on the real exchange rate mentioned in Table 5. The results indicate that a positive shock to gold price leads to a depreciation in the real exchange rate across all regions. On average, this shock in gold price changes corresponds to a quarterly change of approximately -0.01% to -0.03% in the real exchange rate across the various regions. It is also worth noting that this shock is statistically significant for both advanced economies (panel A) and emerging economies (panel B) throughout the entire simulation period. Overall, these findings suggest that an increase in gold price has a noticeable impact on the real exchange rate, resulting in a depreciation across all regions, regardless of their economic development level.

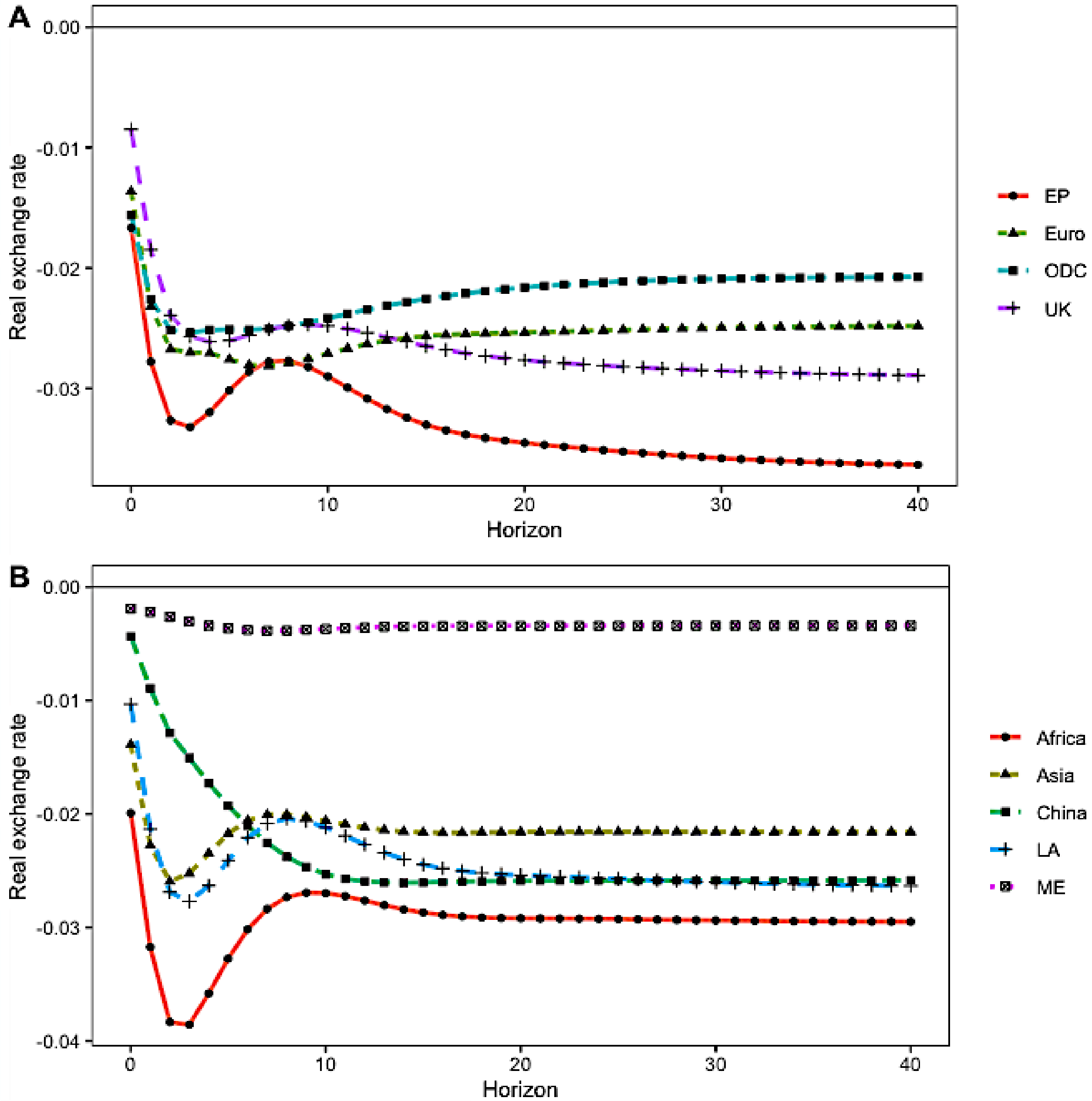

Figure 5. GIRFs of a positive unit (1 s.e.) shock to gold price changes for advanced (panel A) and emerging economies (panel B). For notes, see Figure 2.

For a comprehensive understanding of the significance of the shocks, please refer to the individual responses along with their respective confidence bands, which can be found in Appendix Figure A.4. The findings depicted in Figure 5 align with previous research, reinforcing the notion that the gold market can be considered a hedge against economic recession and currency risk (Sui, Rengifo, and Court 2021; Wang and Lee 2016). For instance, Wang and Lee (2021) utilized a TVR-VAR approach and affirmed the negative response of major currencies (such as USD, euro, and the British pound) to shocks in the price of gold. Additionally, they indicated that gold acts as a hedge against currency depreciation in the short term, although this effect diminishes in the long run.

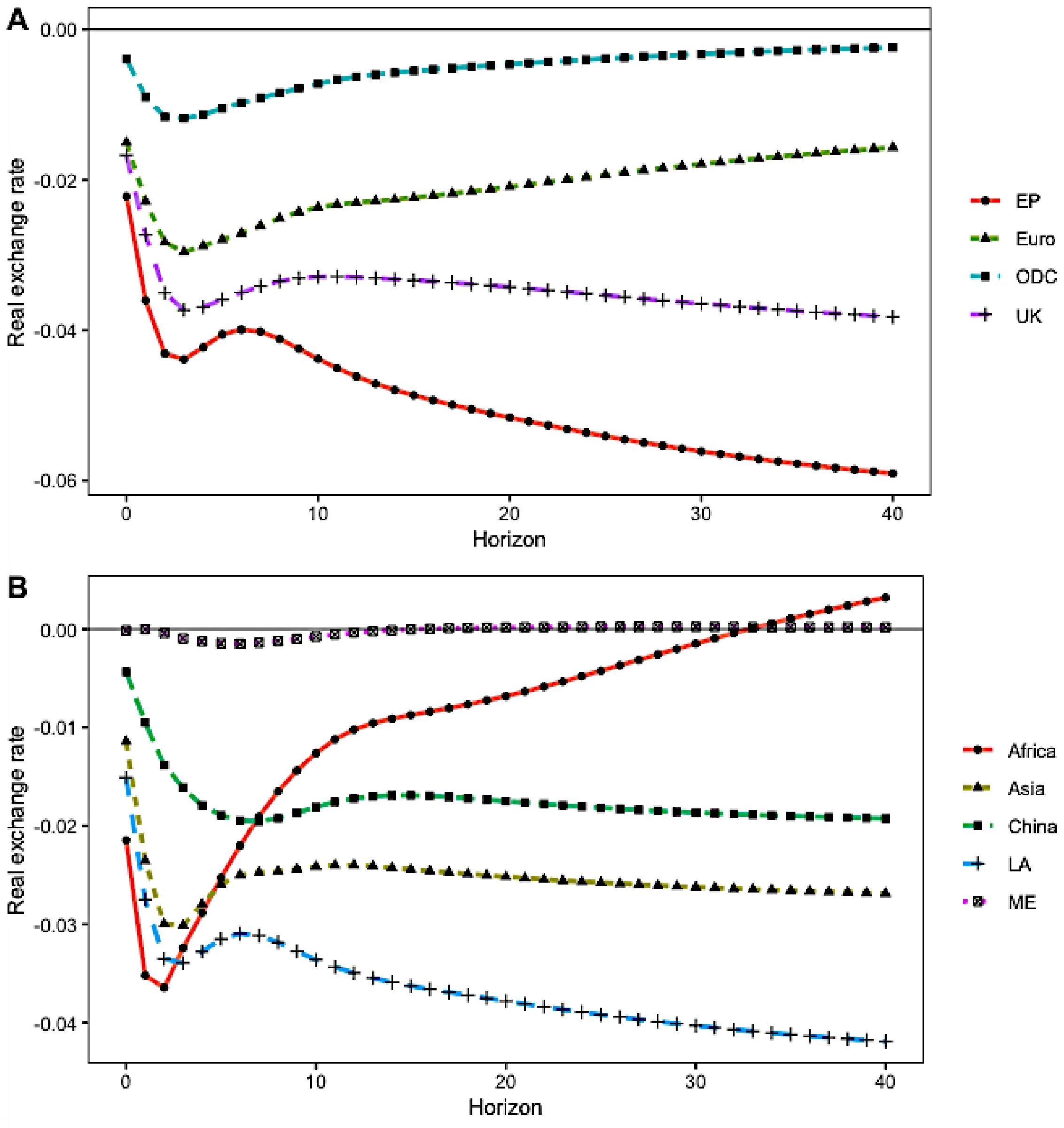

Figure 6. GIRFs of a positive unit (one s.e.) shock to lead prices for advanced (panel A) and emerging economies (panel B). For notes, see Figure 2.

In Figure 6, we present the reactions of the real exchange rate at the regional level to a lead price shock. Our findings reveal that a positive shock in lead price change, measuring one standard error, leads to a noticeable real exchange rate depreciation per quarter, ranging from -0.01% to -0.02%. These effects are particularly pronounced in several specific advanced and emerging economies. To the best of our knowledge, our study is the first to specifically examine the impact of global lead prices on real exchange rate movements using the LASSO and GVAR approaches. It's worth noting that our results align with earlier studies, such as the one conducted by Brown and Hardy (2019), who identified a significant and robust relationship between exchange rate movements and three base metal prices (copper, lead, and nickel), although they employed a somewhat different methodology.

Overall, our research contributes to the existing literature by shedding light on the relationship between lead price shocks and real exchange rate dynamics, offering new insights into the potential drivers of exchange rate movements.

3.3.4.2 Inflation

Figure 7 demonstrates the responses of regional inflation to a shock in crude oil prices. Upon analyzing the data, it is evident that the impact is met with varied reactions, but the responses consistently become positive and stable within the first six quarters after the initial shock. The figure specifically depicts a clear inflationary effect resulting from the oil price shock, observable after the initial six quarters, for both advanced and emerging economies. It is worth noting that the effect seems to dissipate relatively quickly for advanced economies (panel A) compared to emerging economies (panel B). However, it is important to highlight that Middle Eastern countries exhibit a distinct negative impact on inflation as a consequence of the oil price shock, which deviates from the reaction seen in other country groups.

The reactions depicted in Figure 7 align with the current global economic conditions, providing clear evidence that significant historical oil price shocks transmit inflationary pressures worldwide. This observation corroborates the findings of Ha, Kose, and Ohnsorge (2022). For a more in-depth analysis of the shock reactions' significance, please refer to Figure A.5 in the appendix. Galesi and Lombardi (2009) conducted a study examining the impact of oil price hikes on headline inflation. They found that oil price shocks tend to exert inflationary pressures, particularly on advanced economies. Supporting the findings of our simulation, a recent analysis by Ha, Kose, and Ohnsorge (2022) also indicates that the global inflationary trends have been primarily driven by the increase in oil prices. This aligns with the results obtained from our Generalized Impulse Response Functions (GIRFs) regarding the effects of oil price change shocks. Notably, the events in Ukraine in 2022 have once again reaffirmed this causal relationship between oil prices and inflation.

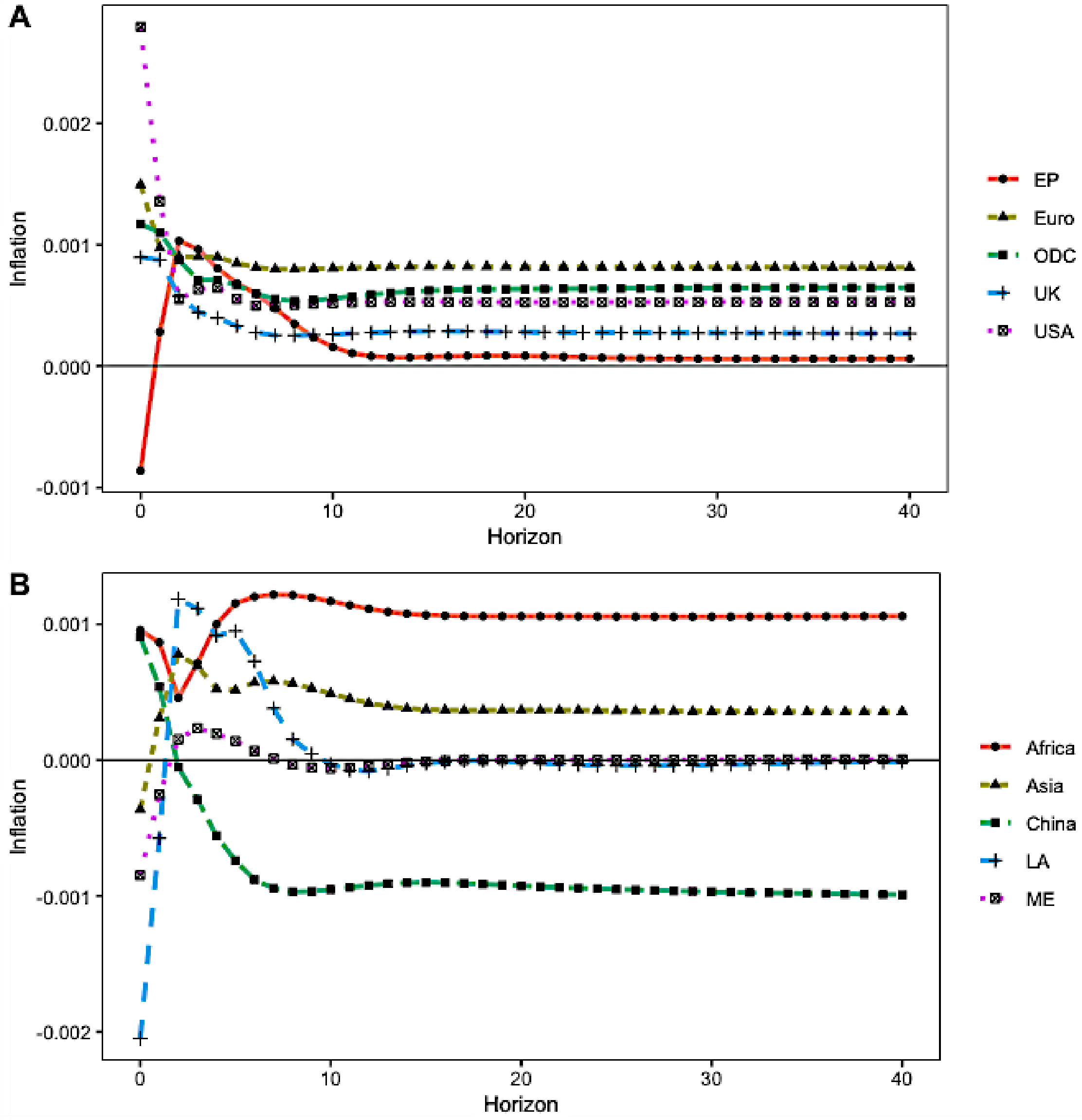

Figure 7. GIRFs of a positive unit (one s.e.) shock to crude oil prices for advanced (panel A) and emerging economies (panel B). For notes, see Fig. 2.

3.3.5 Generalized Forecast Error Variance Decompositions

To further assess the impact of fluctuations in commodity prices on global macroeconomic activities over the next 10 years, we analyzed the variance in macroeconomic variables attributed to each specific commodity price shock. This analysis was performed over a 40-quarter period average using a methodology called generalized forecast error variance decompositions (GFEVDs). In Table 8, we present the proportion of variance explained by different commodity price shocks for various regional and country settings. The results indicate that shocks in copper market prices may account for approximately 1 basis point (for Africa) up to 70 basis points (for China) of the variability in regional output. The strongest effects are observed in China, the euro area, and the UK, where copper market price developments play a significant role in explaining the variation in the global economy. This finding aligns with the observed shock responses illustrated in Figure 3.

Furthermore, we find that increases in crude oil market prices also contribute significantly to regional output variability. For China, crude oil price hikes account for approximately 68 basis points, while in the euro area, Latin America, the UK, and the US, the corresponding figures are 104, 84, 56, and 50 basis points, respectively. Similarly, there is notable variation in the way different regions respond to changes in the real exchange rate when it comes to the prices of gold and lead. These commodities contribute to anywhere between 1 to 44 basis points of the overall variance in the real exchange rate. When it comes to variations in regional inflation, crude oil price fluctuations have an impact of 4 to 64 basis points. However, advanced economies, including the euro area, tend to experience more significant effects due to oil price shocks. This aligns with the fact that oil price increases have historically been a major factor in driving inflationary pressures in recent years.

Table 8. Generalized forecast error variance decompositions (average in %)

	Real GDP		Real exchange rate		Inflation
Regions	Copper	Oil	Gold	Lead	Oil
Africa	0.01	0.01	0.33	0.04	0.45
Asia	0.24	0.34	0.09	0.11	0.33
China	0.70	0.68	0.18	0.06	0.04
Euro area	0.68	1.04	0.44	0.01	0.50
Other European countries	0.07	0.22	0.27	0.38	0.37
Latin America	0.25	0.84	0.14	0.06	0.34
Middle East	0.33	0.20	0.20	0.09	0.03
Other developed countries	0.16	0.15	0.22	0.25	0.64
UK	0.67	0.56	0.22	0.32	0.14
USA	0.02	0.50			0.20

Notes: The points estimate reported are the average of a 40-quarter-ahead forecast error variance (proportion) of the commodity price change explained by conditioning on contemporaneous and future innovations.

3.4 Concluding remarks and policy recommendations

In this study, we employed machine learning techniques such as LASSO and GVAR approaches to analyze the relationship between key macroeconomic variables (output, inflation, and real exchange rate) and commodity market exposures. Our novel approach enabled us to assess the statistical significance of various commodities without any preconceived assumptions about their relevance. By considering a comprehensive set of 55 commodities, we identified the four most significant commodity market segments: crude oil, gold, copper, and lead. These markets seem to play a crucial role in influencing global economic cycles in the contemporary context. In the second stage of our analysis, we investigated the dynamic impacts of price change shocks in these identified markets on the performance of economic regions in both advanced and emerging countries.

Overall, our findings support the notion that traditional markets like copper, oil, and gold significantly contribute to global economic performance. These findings have broader implications, suggesting the growing importance of these commodities in shaping global economic trends. Given the significant influence of crude oil, gold, copper, and lead on global economic cycles, policymakers should encourage diversification of commodity market exposures. This can include promoting the development of other commodity markets, such as renewable energy sources or emerging technologies, to reduce dependency on a few key commodities and mitigate the potential risks associated with their price volatility. Additionally, we propose that achieving optimal stabilization policies for output, inflation, and the development of real exchange rates requires meticulous forecasting exercises for the global commodity prices that hold the greatest significance in general. This is especially important for individual economies.

APPENDIX 3.A

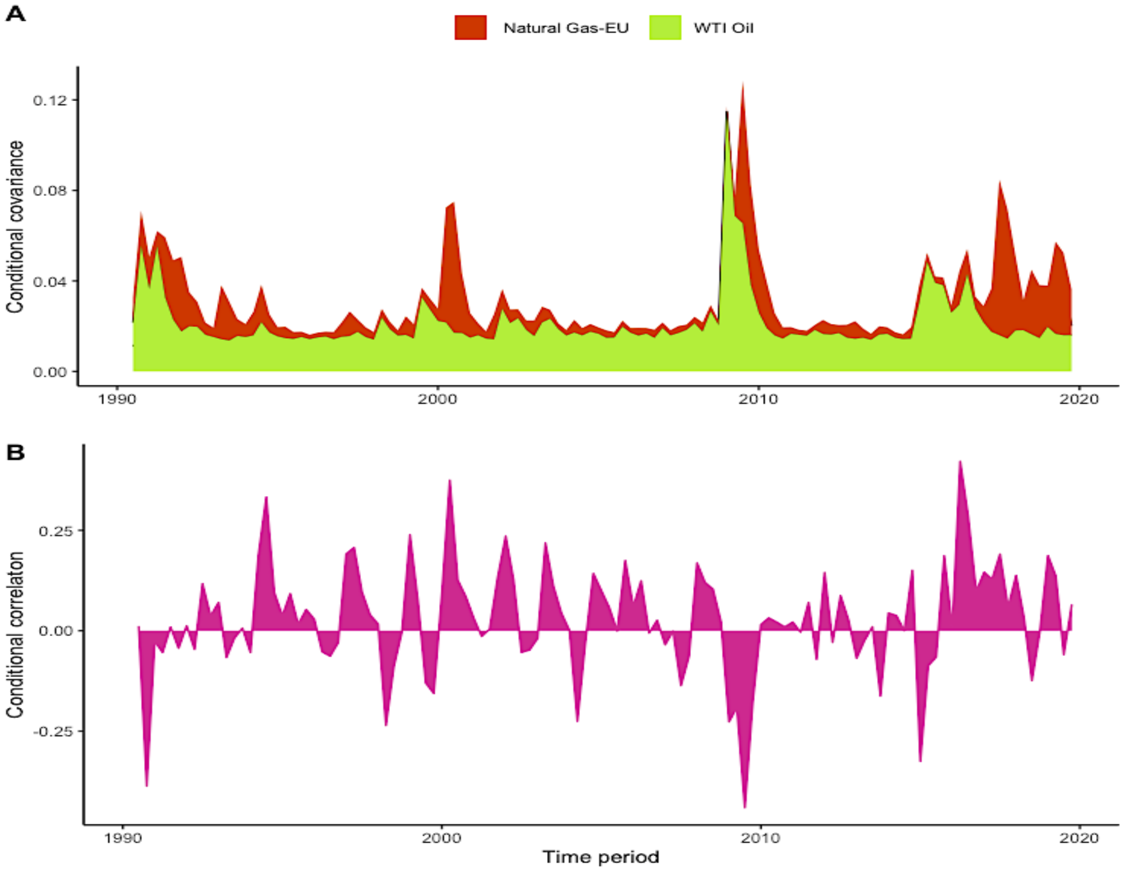

Figure A.1. The dynamic conditional covariance (panel A) and correlation (panel B) between the EU natural gas and WTI crude oil price changes.

Note: The authors' estimations are based on the DCC-GARCH (1,1)-model for log price changes

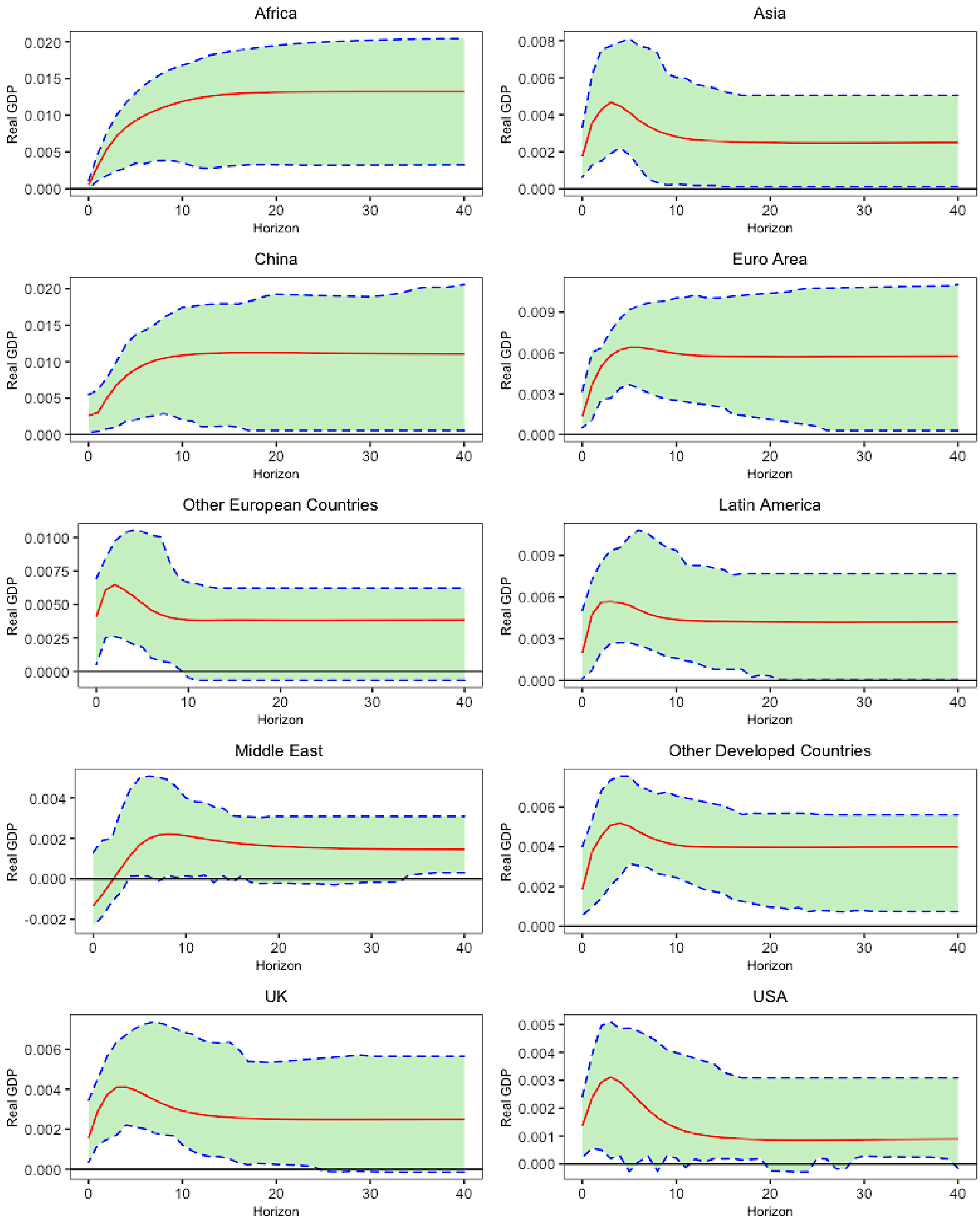

Figure A.2. The response of real GDP to a unit (one s.e.) copper price shock with the 95% confidence band for the regions.

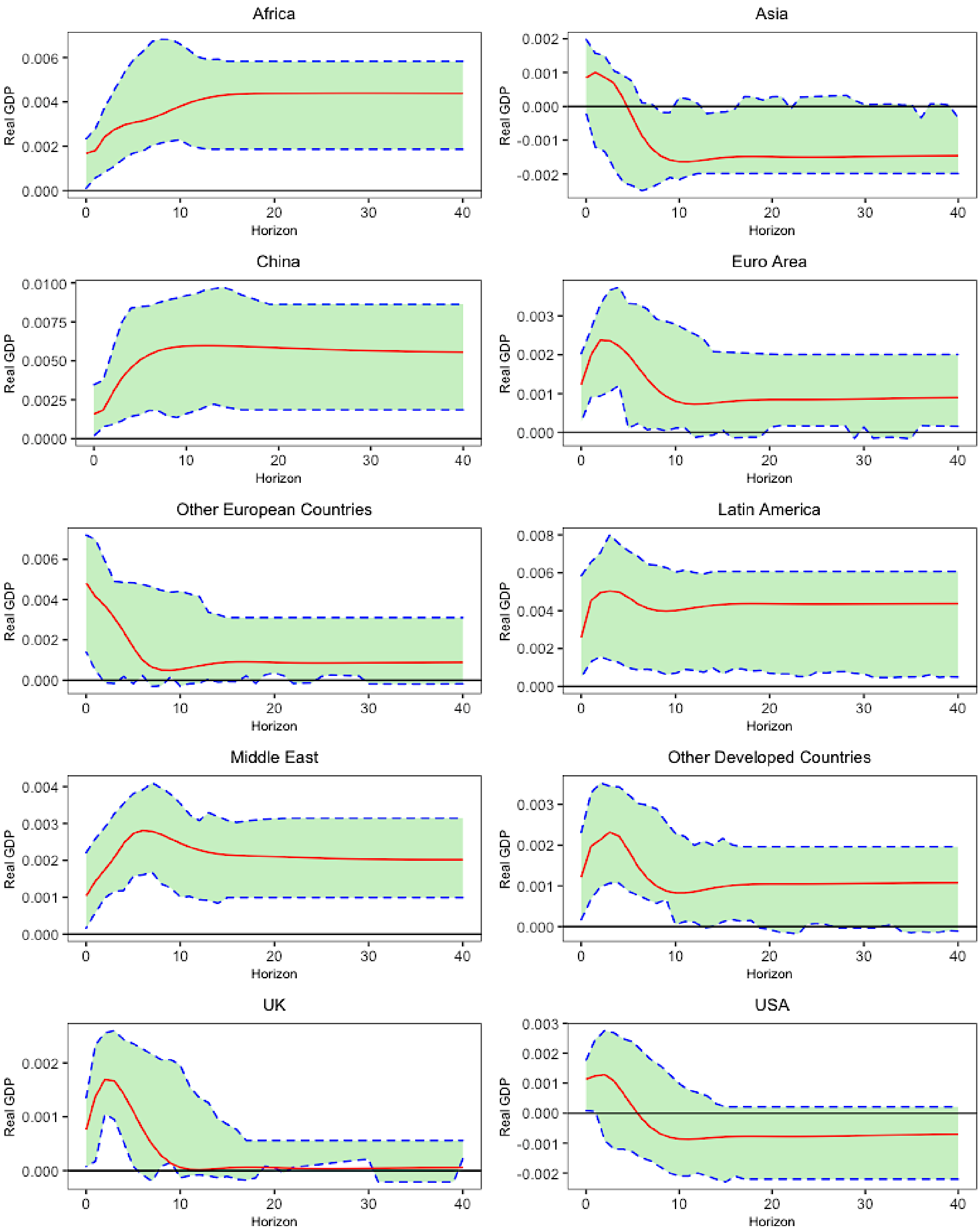

Figure A.3. The response of real GDP to a unit (one s.e.) oil price shock with the 95% confidence band for the regions.

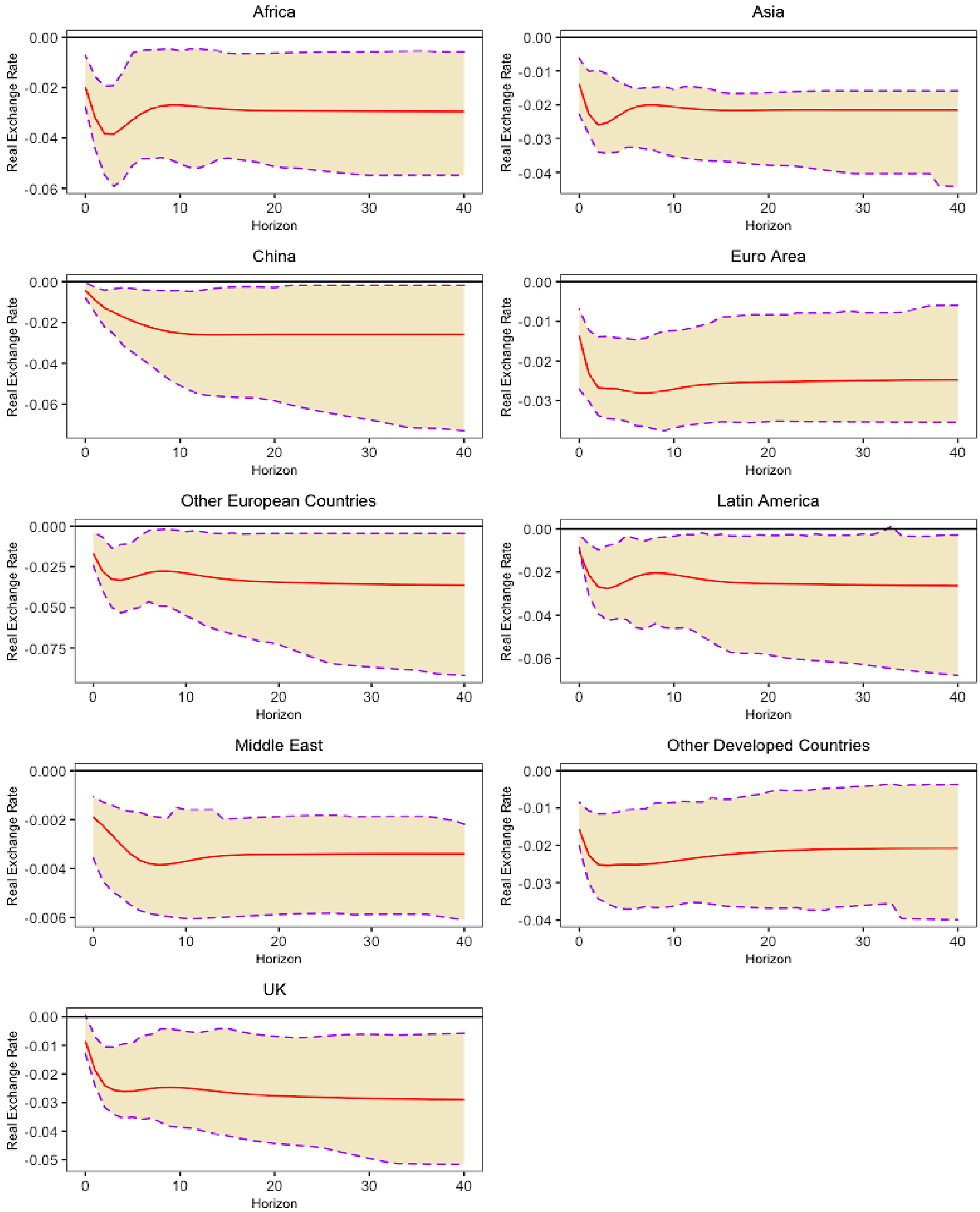

Figure A.4. The response of real exchange rate to a unit (one s.e.) gold price shock with the 95% confidence band for the regions.

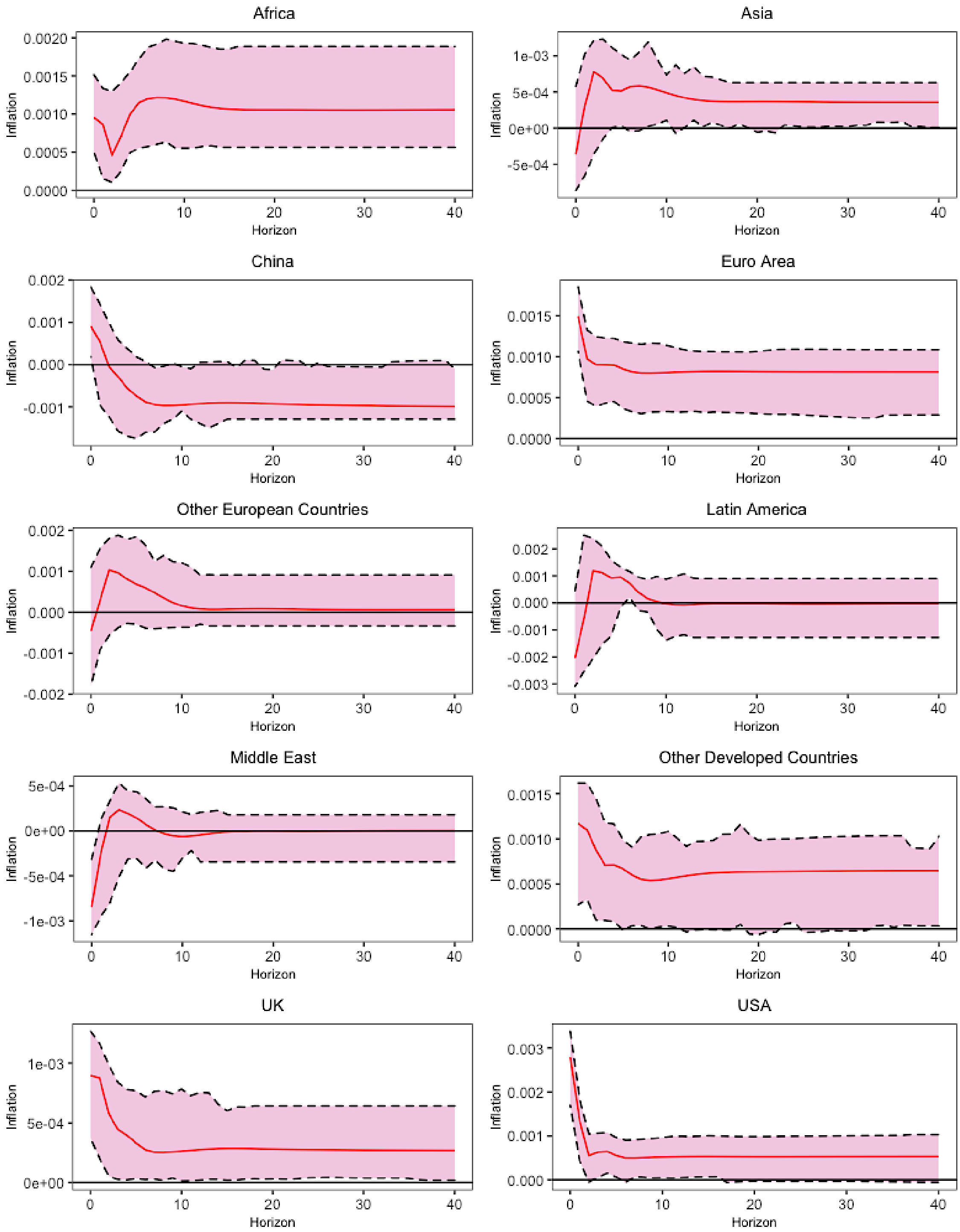

Figure A.5. The response of inflation to a unit (one s.e.) oil price shock with the 95% confidence band for the regions.

Table A.1. Estimates for the effects on macroeconomy from the LASSO-selected commodity market returns – *pre-crisis 1990Q1- 2006Q4*

	Output (real GDP)		Inflation	Real exchange rate	
Country	Copper	Oil	Oil	Gold	Lead
Argentina		0.02 (0.01) ***			
Australia				-0.15 (0.04) ***	
Austria	0.01 (0.00) **		0.01 (0.00) ***		-0.05 (0.02) **
Belgium	0.02 (0.00) **		0.01 (0.00) ***	-0.15 (0.05) ***	-0.23 (0.06) ***
Brazil				-0.26 (0.08) ***	-0.10 (0.03) ***
Canada		0.02 (0.01) ***	0.01 (0.00) **	-0.15 (0.05) ***	
China					-0.11 (0.04) ***
Chile	0.01 (0.01) *			-0.18 (0.07) ***	-0.09 (0.04) ***
Finland			0.02 (0.01) **	-0.12 (0.05) **	
France		0.01 (0.00) **	0.01 (0.0) ***	-0.18 (0.04) ***	
Germany	0.01 (0.00) *		0.02 (0.00) ***	-0.13 (0.05) **	-0.09 (0.02) ***
India	0.01 (0.01) *			-0.11 (0.05) **	
Indonesia				-0.22 (0.07) ***	-0.08 (0.03) ***
Italy	0.02 (0.00) **			-0.15 (0.05) ***	
Japan				-0.30 (0.06) ***	-0.14 (0.04) ***
Korea		0.02 (0.01) *			
Malaysia		0.01 (0.00) *	0.02 (0.00) **	-0.20 (0.06) ***	
Mexico	0.02 (0.01) *				
Netherlands					
Norway	0.01 (0.01) **	0.02 (0.01) **		-0.17 (0.06) ***	-0.17 (0.04) ***
New Zealand			0.01 (0.00) ***	-0.23 (0.07) ***	
Peru					
Philippines		0.01 (0.00) *			-0.20 (0.10) **

	Output (real GDP)		Inflation	Real exchange rate	
Country	Copper	Oil	Oil	Gold	Lead
South Africa		0.01 (0.00) **		0.41 (0.15) ***	
Saudi Arabia		0.02 (0.00) ***		-0.04 (0.01) ***	
Singapore	0.04 (0.01) ***		0.01 (0.00) *		
Spain			0.01 (0.00) ***	-0.11 (0.05) **	-0.09 (0.03) ***
Sweden				-0.15 (0.04) ***	
Switzerland	0.02 (0.01) **	0.01 (0.00) *	0.01 (0.00) **	-0.16 (0.05) ***	-0.06 (0.02) ***
Thailand	0.02 (0.00) ***		0.02 (0.00) ***	-0.35 (0.06) ***	
Turkey	0.01 (0.00) **	0.01 (0.01)			
United Kingdom					
USA			0.02 (0.00) ***		
Number (#) of significant effects/total # of countries	12/33	10/33	13/33	21/33	12/33

Notes: This table presents the LASSO-selected commodities (4 out of the 55 commodity indices in row 2), that have the strongest impact on global macroeconomic variables (real GDP, inflation, and real exchange rate) for the sub sample; pre-crisis 1990Q1- 2006Q4. The model is estimated using OLS (Eq. 4) with robust standard errors in parentheses. Here *, **, *** denotes the 10, 5, and 1% levels of statistical significance. Further notations see Table 5

Table A.2. Estimates for the effects on macroeconomy from the LASSO-selected commodity market returns – *post-crisis 2010Q1- 2019Q4*

	Output (real GDP)		Inflation	Real exchange rate	
Country	Copper	Oil	Oil	Gold	Lead
Argentina		0.03 (0.01) ***			
Australia			0.01 (0.00) ***	-0.24 (0.04) ***	0.18 (0.04) ***
Austria	0.01 (0.00) **	0.02 (0.01) *	0.02 (0.00) ***	-0.19 (0.05) ***	
Belgium	0.01 (0.00) **	0.01 (0.00) *	0.01 (0.00) ***	-0.14 (0.05) ***	-0.05 (0.02) **
Brazil		0.03 (0.01) ***		-0.23 (0.08) ***	-0.21 (0.06) ***
Canada			0.01 (0.00) **	-0.18 (0.05) ***	-0.10 (0.03) ***
China	0.00 (0.01)				
Chile	0.02 (0.01) **			-0.21 (0.07) ***	-0.14 (0.04) ***
Finland	0.02 (0.01) **	0.02 (0.01) **	0.02 (0.01) **	-0.17 (0.05) ***	-0.12 (0.04) ***
France	0.01 (0.00) **	0.01 (0.00) **	0.01 (0.0) ***	-0.18 (0.04) ***	
Germany	0.01 (0.00) *		0.02 (0.00) ***	-0.12 (0.05) **	-0.09 (0.03) ***
India					-0.05 (0.02) **
Indonesia	0.01 (0.00) *	0.01 (0.02)		-0.39 (0.22) ***	
Italy	0.02 (0.00) **	0.02 (0.01) *	0.01 (0.00) *	-0.16 (0.05) ***	-0.012 (0.03) ***
Japan	0.02 (0.00) ***			-0.32 (0.06) ***	0.09 (0.04) **
Korea	0.02 (0.01) *	0.02 (0.01) *		-0.21 (0.07) **	-0.15 (0.04) ***
Malaysia		0.02 (0.00) **	0.02 (0.00) **	-0.21 (0.06) ***	
Mexico	0.02 (0.01) *		-0.01 (0.01)		
Netherlands				-0.19 (0.05) **	-0.06 (0.03) **
Norway	0.02 (0.01) **	0.02 (0.01) **	0.01 (0.00) *	-0.23 (0.06) ***	
New Zealand			0.01 (0.00) ***	-0.23 (0.07) ***	-0.19 (0.04) ***
Peru	0.02 (0.01) *				
Philippines	0.02 (0.01) *	0.01 (0.00) *		-0.09 (0.05) *	-0.07 (0.03) **
South Africa	0.01 (0.01)	0.01 (0.00) **	0.00 (0.01)	0.39 (0.15) ***	-0.21 (0.10) **

Country	Output (real GDP)		Inflation	Real exchange rate	
	Copper	Oil	Oil	Gold	Lead
Saudi Arabia	-0.00 (0.01)	0.01 (0.00) *		-0.04 (0.01) ***	
Singapore	0.04 (0.01) ***		0.01 (0.00) *	-0.16 (0.04) ***	-0.015 (0.02)
Spain			0.02 (0.00) ***	-0.12 (0.05) **	
Sweden	0.02 (0.01) *	0.01 (0.00) *		-0.15 (0.04) ***	-0.09 (0.03) ***
Switzerland	0.02 (0.01) **	0.01 (0.00) *	0.01 (0.00) **	-0.16 (0.05) ***	
Thailand	0.02 (0.00) ***		0.02 (0.00) ***	-0.30 (0.06) ***	-0.06 (0.02) ***
Turkey	0.01 (0.00) **	0.02 (0.01) **			
United Kingdom			0.01 (0.01)		0.01 (0.07)
USA			0.01 (0.00) ***		0.03 (0.05)
Number (#) of significant effects/total # of countries	19/33	16/33	16/33	25/33	17/33

Notes: This table presents the LASSO-selected commodities (4 out of the 55 commodity indices in row 2), that have the strongest impact on global macroeconomic variables (real GDP, inflation, and real exchange rate) for the sub sample; post-crisis 2010Q1- 2019Q4. The model is estimated using OLS (Eq. 4) with robust standard errors in parentheses. Here *, **, *** denotes the 10, 5, and 1% levels of statistical significance. Further notations see Table 5.

Table A.3. Summary statistics for the domestic variables

	Real GDP			Inflation			Real exchange rate		
Country/region	Mean	Std. dev.	J. B	Mean	Std. dev.	J. B	Mean	Std. dev.	J. B
Argentina	4.77	0.31	9.16	0.06	0.16	16761.50	-4.22	0.30	1.84
Australia	4.72	0.28	8.21	0.01	0.01	404.69	-4.46	0.33	11.22
Brazil	4.74	0.23	10.75	0.12	0.27	485.28	-4.29	0.30	3.85
Canada	4.66	0.21	9.66	0.00	0.00	164.78	-4.47	0.25	13.07
China	5.13	0.87	9.41	0.01	0.01	225.24	-2.69	0.31	10.90
Chile	4.77	0.38	6.85	0.01	0.01	173.85	1.56	0.24	6.82
Euro area	4.63	0.12	9.31	0.00	0.00	4.87	-4.90	0.19	5.51
India	4.92	0.59	8.06	0.02	0.01	11.30	-1.07	0.32	13.20
Indonesia	4.88	0.39	7.11	0.02	0.03	2507.13	3.99	0.30	32.96
Japan	4.65	0.07	7.51	0.00	0.00	72.10	0.11	0.15	1.42
Korea	4.75	0.36	8.08	0.01	0.01	243.36	2.23	0.20	6.44
Malaysia	4.78	0.43	4.76	0.01	0.01	248.94	-3.48	0.16	6.80
Mexico	4.66	0.23	7.41	0.02	0.02	769.47	-2.34	0.21	12.18
Norway	4.57	0.20	9.59	0.01	0.01	88.50	-2.75	0.21	7.54
New Zealand	4.98	0.22	5.48	0.01	0.00	143.68	-4.27	0.33	10.84
Peru	4.86	0.42	8.79	0.06	0.23	16342.79	-3.58	0.25	3.66
Philippines	4.86	0.40	8.11	0.01	0.01	331.39	-1.07	0.27	11.16

	Real GDP			Inflation			Real exchange rate		
Country/region	Mean	Std. dev.	J. B	Mean	Std. dev.	J. B	Mean	Std. dev.	J. B
South Africa	4.76	0.25	11.94	0.02	0.01	10.66	-2.92	0.19	31.87
Saudi Arabia	4.87	0.37	12.24	0.00	0.01	194.44	-3.43	0.19	15.95
Singapore	4.76	0.46	7.92	0.00	0.01	8.05	-4.27	0.25	9.96
Sweden	4.69	0.21	7.66	0.00	0.01	351.54	-2.65	0.16	0.93
Switzerland	4.68	0.14	9.58	0.00	0.00	26.06	-4.43	0.25	10.41
Thailand	4.81	0.31	5.59	0.01	0.01	29.56	-1.19	0.24	10.06
Turkey	4.78	0.35	8.05	0.07	0.06	30.50	-5.32	0.38	11.41
UK	4.66	0.17	10.26	0.01	0.00	533.81	-5.16	0.20	8.66
USA	4.65	0.20	8.30	0.01	0.00	474.66			

Notes: This table presents the summary statistics for the domestic variables at levels, without taking the first difference. J.B denotes the Jarque-Bera test statistics for series normality at a 5% significance level; Std dev. = standard deviation.

Table A.4. Summary statistics for the country-specific foreign variables

	Real GDP*			Inflation*			Real exchange rate*		
Country/region	Mean	Std. dev.	J. B	Mean	Std. dev.	J. B	Mean	Std. dev.	J. B
Argentina	4.77	0.32	9.24	0.04	0.09	448.1	-3.23	0.23	9.74
Australia	4.85	0.43	8.40	0.01	0.01	53.4	-2.04	0.22	12.85
Brazil	4.79	0.37	8.47	0.01	0.02	8614.5	-2.96	0.18	10.10
Canada	4.70	0.26	7.89	0.01	0.01	134.2	-2.86	0.20	12.67
China	4.71	0.24	7.60	0.01	0.01	387.1	-2.14	0.19	9.75
Chile	4.80	0.38	8.76	0.02	0.03	953.1	-2.78	0.21	12.89
Euro area	4.76	0.33	8.46	0.01	0.01	232.4	-3.27	0.22	12.85
India	4.78	0.34	8.52	0.01	0.01	192.6	-2.93	0.21	12.71
Indonesia	4.80	0.38	7.99	0.01	0.01	100.2	-2.28	0.21	12.30
Japan	4.83	0.43	8.33	0.01	0.01	74.2	-2.37	0.24	14.05
Korea	4.84	0.43	8.67	0.01	0.01	125.2	-2.49	0.22	13.52
Malaysia	4.80	0.38	8.08	0.01	0.01	42.7	-2.13	0.22	12.59
Mexico	4.71	0.27	7.93	0.01	0.01	172.3	-2.78	0.21	13.61
Norway	4.68	0.21	8.64	0.01	0.01	118.8	-4.21	0.18	8.74
New Zealand	4.80	0.38	8.29	0.01	0.01	27.3	-2.84	0.24	13.23
Peru	4.78	0.36	8.53	0.02	0.02	776.1	-2.71	0.21	13.04
Philippines	4.78	0.34	7.94	0.01	0.01	18.8	-1.87	0.20	11.38
South Africa	4.79	0.35	8.59	0.01	0.01	182.2	-3.12	0.21	13.37
Saudi Arabia	4.79	0.36	8.20	0.01	0.01	74.5	-1.86	0.21	13.11
Singapore	4.81	0.39	7.41	0.01	0.01	22.6	-1.71	0.21	11.61

Country/region	Real GDP* Mean	Std. dev.	J. B	Inflation* Mean	Std. dev.	J. B	Real exchange rate* Mean	Std. dev.	J. B
Sweden	4.67	0.20	8.38	0.01	0.01	55.1	-4.18	0.19	8.54
Switzerland	4.70	0.23	8.30	0.01	0.01	94.7	-4.20	0.19	9.92
Thailand	4.79	0.36	8.12	0.01	0.01	95.1	-2.08	0.20	11.54
Turkey	4.73	0.27	8.48	0.01	0.01	100.5	-3.79	0.20	10.84
UK	4.70	0.23	8.32	0.01	0.01	46.4	-4.02	0.20	9.10
USA	4.77	0.34	8.60	0.01	0.01	212.3	-3.06	0.21	13.48

Notes: This table shows the summary statistics of the country-specific foreign variables at levels, excluding the first difference. For notes, see A.1.

Table A.5. Summary statistics for the global variables

Global variables	Mean	Std. dev.	Jarque-Bera
Crude Oil	4.51	0.63	9.02
Copper	4.31	0.61	12.15
Gold	3.88	0.64	14.34
Lead	3.94	0.65	11.35

Table A.6. VARX*, Weak exogeneity lag order and number of cointegrating relationships in the country-specific models

	VARX* lag order of individual models		Lag order of weak exogeneity regression		Cointegrating relations
Country/ region	Domestic variables (p_i)	Foreign variables (q_i)	Domestic variables (p^*)	Foreign variables (q^*)	Number (#)
Argentina	2	1	2	1	2
Australia	1	1	1	1	3
Brazil	2	1	2	1	2
Canada	2	1	1	1	3
China	2	1	2	1	2
Chile	2	1	2	1	2
Euro area	2	1	1	1	1
India	2	1	1	1	2
Indonesia	2	1	1	1	3
Japan	2	1	1	1	2
Korea	2	1	1	1	3
Malaysia	1	1	1	1	2
Mexico	1	1	1	1	2
Norway	2	1	1	1	3
New Zealand	2	1	1	1	3
Peru	2	1	1	1	2
Philippines	2	1	1	1	3
South Africa	2	1	1	1	2
Saudi Arabia	2	1	1	1	1
Singapore	2	1	1	1	1

Country/ region	VARX* lag order of individual models		Lag order of weak exogeneity regression		Cointegrating relations
	Domestic variables (p_i)	Foreign variables (q_i)	Domestic variables (p^*)	Foreign variables (q^*)	Number (#)
Sweden	2	1	1	1	2
Switzerland	1	1	1	1	3
Thailand	2	1	1	1	2
Turkey	2	1	1	1	1
UK	1	1	1	1	2
USA	2	1	1	1	2

Notes: This table shows the lag order (*p, q*) in the VARX* estimation of Eq. 5 and the weak exogeneity estimation of Eq. 7, respectively. The lag orders are selected based on the Akaike information criterion (AIC). The table also reports the number of cointegrating relations found for each country model in Eq. 7.

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4 GREENFLATION, RENEWABLE AND FOSSIL COMMODITY CURRENCIES

Abstract.
This study investigates the impact of greenflation on the global economy's transition towards a greener future and explores the real exchange rate exposures among industrialized and emerging countries. Our findings suggest that greenflation primarily stems from factors within the global commodity demand chain, characterized by increasing renewable energy consumption, higher imports of commodities essential for green energy production, climate change, and global inflation. Our results demonstrate that these drivers of greenflation are closely interconnected at both regional and global levels. Furthermore, the study observes that fluctuations in fossil commodity prices contribute to long-term equilibrium movements in the real exchange rates of Norway and Saudi Arabia. Conversely, the renewable energy sector significantly influences the real exchange rates of Malaysia, New Zealand, Belgium, and South Africa. Overall, the research underscores the critical roles played by demand chain factors, climate change, and inflation in driving up energy-related commodity prices, consequently impacting the currency dynamics of specific countries.

Keywords: exchange rates, commodity currency, greenflation, commodity prices
JEL Codes: F31, F41, C32

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4.1 Introduction

Inflation has made a comeback in the global economies following the pandemic years of 2020-2021. It has surpassed the central banks' target levels to a significant extent. This surge in inflation can be attributed, in part, to various policies implemented to reduce greenhouse gas emissions. Furthermore, the process of decarbonization has become more expensive, and the costs are closely tied to the prices of commodities, particularly those related to the production of fossil and renewable energy sources (Mier and Weissbart, 2020). The impact of the inflation crisis related to commodities is felt worldwide, but its magnitude may differ across countries based on their production structures. Hence, this paper aims to analyze the effects of transitioning towards sustainable energy production on commodity price inflation (i.e., the upward movement of commodity prices) and the exposure of real exchange rates among both industrialized and emerging economies.

It is expected that the transition towards green energy and the decarbonization of the economy would lead to a decrease in demand and prices for fossil energy sources (Shuai et al., 2017). However, we have witnessed an opposite trend lately, with a rapid increase in prices across various forms of fossil energy sources. This surge can be attributed, in part, to the growing demand for fossil energy and a lack of investments in renewable energy production in the near term. This goes against the common expectation that rising energy prices would attract new investments to meet the demand. Despite policies like the introduction of ESG investment criteria aimed at directing financial resources towards renewable energy production, the shift in supply towards renewable sources has not been successful (Yang et al., 2022; Wang, Sun, and Iqbal, 2022). Consequently, this situation continues to put pressure on the demand for fossil energy production.

In accordance with the rise in fossil energy prices, there has been a significant increase in demand for commodities necessary for the production of renewable energy sources, such as wind power and solar energy. Consequently, this trend is giving rise to what is often referred to as "greenflation"[18]. For instance, as a result of government and investor support strategies to mitigate climate change, the prices of key metals and minerals like aluminum, copper, lithium, and nickel-cobalt have surged by more than 90 percent in 2021 (IEA 2021;

[18] Greenflation refers to the phenomenon of rising prices in key metals and minerals commodities that are essential for the production of renewable energy sources, such as copper, aluminium, lithium, cobalt, and others. These materials play a crucial role in various renewable technologies like solar power, wind power, electric cars, and other sustainable energy solutions (IEA 2021; Luke et al., 2022). The definition of greenflation can also be found in a speech given by Isabel Schnabel, an executive member of the European Central Bank, which is available at: https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp220317_2~dbb3582f0a.en.html and also, by Ruchir Sharma (2021)-Financial times available at: https://www.ft.com/content/49c19d8f-c3c3-4450-b869-50c7126076ee

Chowdhury 2021). This rise in demand for metals and mineral commodities, coupled with constrained supply due to reduced investment in carbon-emitting production processes like smelting, has had a broader impact on commodity prices. These dynamics continue to drive up global prices of commodities required for renewable energy production, consequently affecting the terms of trade performance of both exporting and importing countries. As a consequence, these terms-of-trade shocks caused by fluctuations in global commodity prices may have long-term effects on the equilibrium real exchange rates of countries engaged in the export and import of commodities.

In this context, the research paper examines the effects of the shift towards green energy production on the upward trend in prices of metals and minerals within the commodity sector (referred to as "greenflation"), as well as the vulnerability of currencies tied to the production of these critical commodities - both in the fossil and renewable energy sectors. The study recognizes that different currencies will not be uniformly impacted by commodity price inflation. Therefore, the goal is to identify currencies that are particularly exposed to changes in fossil energy prices, which we refer to as "*Fossil Currencies*" *(FC*), and currencies that are especially susceptible to changes in prices of commodities related to renewable energy, known as "*Renewable Currencies*" *(RC*).

Previous economic literature has identified commodity currencies as those whose exchange rates are strongly influenced by changes in commodity prices (Chen and Rogoff, 2003; Cashin et al., 2004; Kohlseen et al., 2016). Building upon this existing research, our study aims to contribute further by categorizing currencies into two groups: *Renewable Currencies (RC)* and *Fossil Currencies (FC)*. The classification is based on their responsiveness to fossil energy prices (FC) and prices of commodities used in the production of green energy (RC). Consequently, our research aligns with a substantial body of literature focused on understanding deviations from the purchasing power parity rate in real exchange rates (Ricci et al., 2013; Rossi, 2013; Cashin et al., 2004; Chen and Rogoff, 2003; Rogoff, 1996). However, our contribution primarily lies in the commodity-currencies literature, as we specifically examine sub-commodity sectors such as metals-minerals and energy (fossil) commodity markets. These sectors are crucial in both global economic development and the ongoing transition towards a greener economy. Our focus on these two major sub-sectors is motivated by the following reasons.

Many studies have utilized broad-based commodity indices (Ricci et al., 2013; Cashin et al., 2004; Chen and Rogoff, 2003) or focused on individual commodity prices, such as oil, to explore the relationship between real exchange rates and commodity prices (Chen and Chen, 2007; Habib and Kalamova, 2007; Bodart et al., 2012). For example, Cashin et al. (2004) examined a broad-based index representing 58 commodity-exporting developing countries and found significant evidence of a long-run equilibrium relationship between real commodity prices and real effective exchange rates for approximately one-third of the countries in their study. Similarly, Chen and Rogoff (2003) investigated the real exchange rate and real commodity price dynamics of Canada, Australia, and

New Zealand using a broad-based index. Their findings indicated a strong positive influence of real commodity prices on the real effective exchange rates of these respective countries. Additionally, Coudert et al. (2008) observed similar evidence for a large group of oil and non-oil commodity exporters.

Studies focusing on individual commodity prices, such as Bodart et al. (2012), examined 42 specific commodities across 68 countries. They discovered that the price of a country's dominant commodity had significant long-run effects on the real exchange rate, particularly when the export share of the leading commodity was high in the total merchandise exports. For instance, in the case of individual commodities like oil, Habib and Kalamova (2007) investigated major oil-producing countries like Russia, Norway, and Saudi Arabia. Their findings supported a positive long-run relationship between the real oil price and the real effective exchange rate for these countries. The determination of the long-run equilibrium real exchange rate has been explored using various empirical approaches. This includes panel cointegration techniques (Ricci et al., 2013; Coudert et al., 2008; Chen and Chen, 2007) as well.

In addition, our focus is on examining the reactions of the metal-mineral commodity sector to macroeconomic factors and other influences that may impact the development of greenflation, particularly in the context of the transition towards sustainable energy production and its effect on the rising prices of the metal/mineral commodity market. In the second stage of our study, we analyze the commodity sub-sector price development to specifically investigate the impact of increasing prices in energy-related commodity markets on the currencies of 26 advanced and emerging countries. We utilize an annual dataset covering the period from 1980 to 2021. To the best of our knowledge, this study represents the first empirical investigation into the role of the transition towards sustainable green energy production as a driver of commodity market-related impacts on greenflation, as well as the valuation of country-level exchange rates.

The initial findings of our research indicate that "greenflation" is primarily influenced by global factors within the commodity demand chain. These factors are characterized by the increasing consumption of renewable energy, the growing import of metal commodities necessary for green energy production, as well as climate change and global inflation. These factors have a substantial positive impact on metal-mineral commodity prices regionally and globally. After controlling for the effects of the supply side on greenflation, our results demonstrate that commodity supply-chain factors do not significantly contribute to greenflation. This means that supply considerations do not play a substantial role in driving greenflation. The second part of our study focuses on examining the role of economic fundamentals and the behavior of the real exchange rate. Our empirical evidence emphasizes the crucial role played by fluctuations in the prices of real commodities (fossil and renewable energy market commodity sub-sectors) in explaining the movements of long-run equilibrium real exchange rates. We have conducted analyses at both the panel and country levels to substantiate these findings.

Additionally, we also controlled for the Balassa-Samuelson effect, which was proxied by productivity differentials, and the role of real interest rate differentials in explaining the deviations of the long-run equilibrium real exchange rates from the purchasing power parity (PPP) equilibrium. Our observations revealed that both productivity and real interest rate differentials are important fundamentals for explaining the long-run equilibrium real exchange rate dynamics. Furthermore, the country-level results indicated that the real exchange rates of Norway and Saudi Arabia, both significant producers of fossil energy (as highlighted in SEI et al., 2021), are associated with long-run developments in fossil commodity prices, consistent with the findings of Habib and Kalamova (2007). Consequently, these currencies can be considered as "*fossil currencies*." Additionally, our results suggested that the real exchange rate developments of Australia and Mexico are associated with both fossil and renewable commodity price index movements. This finding aligns with the research of Cashin et al. (2004), who also identified Australia's currency as a commodity currency using a broad-based (general) commodity index.

Finally, we found a notable long-run impact of renewable energy-related commodity prices on the real exchange rates of Malaysia, New Zealand, Belgium, and South Africa. Consequently, these currencies can be referred to as "*renewable currencies*." To ensure the robustness and consistency of our results, we conducted an alternative approach as a robustness check for modeling the impact of long-run economic fundamentals on real exchange rates, and the results remained robust.

The remaining sections of this paper are structured as follows. Section 4.2 outlines the empirical methods that were employed in this study. Section 4.3 provides details about the data sources used and describes the dataset. In Section 4.4, the empirical findings are presented and discussed. Finally, Section 4.5 concludes the paper by summarizing the key results and discussing their implications for policy.

4.2 Empirical Methods

This section provides an overview of the empirical methods used to examine the impact of the transition towards sustainable energy production on greenflation. The analysis considered various potential factors that could contribute to both the demand side and supply side effects on greenflation[19] which will be discussed in detail in the subsequent section. In the first estimation, we utilized a simple benchmark (global) demand model in reduced form represented as[20]

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[19] Greenflation is measured based on the (log) changes in the prices of the metals-minerals commodity sector. For definition see footnote 1 above.

[20] Based on the unit root test results reported in Table 2a panel 2 the global variables followed an I(1) process i.e., they were non-stationary in levels, so we estimated already Equation (1) in the first difference form.

$$\Delta gf_t = \gamma_0 + \gamma_1 \Delta rec_t + \gamma_2 \Delta sec_t + \gamma_3 \Delta wec_t + \gamma_4 \Delta mp_t + \gamma_5 \Delta gp_t + \epsilon_t, \quad (1)$$

where gf_t denotes greenflation at time t, rec_t represents (global) renewable energy consumption at time t, sec_t denotes (global) solar energy consumption at time t, wec_t the (global) wind energy consumption at time t, mp_t the (global) metals imports share of total merchandise imports at time t (in %), and lastly, gp_t denotes (global) productivity at time t. In addition, Δ denotes (log) differenced values of the variables and $\gamma_i (i = 1, \dots, 5)$ denotes the coefficient estimates on the respective 5 variables. Finally, ϵ_t is the innovation expected to be iid (0, σ^2). Furthermore, Equation (1) is augmented to control for the supply side factors, namely, the (global) metal exports, (global) inflation rate (USA PPI), and climate change risk. All these first-stage regressions are performed using the Newey-West (1987) estimator to control for potential heteroskedasticity and autocorrelation (HAC) in the innovation term.

In the second part of our paper, we conducted an examination of the long- and short-run relationships between the real exchange rate and its fundamental factors. These factors included the real commodity price indices, productivity differentials, and real interest rate differentials. Before performing the estimation, we conducted unit root and cointegration tests to ensure the validity of the data. Based on the results of these tests, we proceeded with panel regression using the Panel Autoregressive Distributed Lag (ARDL) approach[21] represented as,

$$\Delta y_{it} = \alpha_i \left(y_{i,t-1} - \theta_i' x_{it} \right) + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}'^* \Delta x_{i,t-j} + \mu_i + \epsilon_{it}, \quad (2)$$

where $\alpha_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$, $\theta_i = \sum_{j=0}^{q} \delta_{ij} / (1 - \sum_k \lambda_{ik})$, $\lambda_{ij}^* = -\sum_{m=j+1}^{p} \lambda_{im}$,

$j = 1,2, \dots, p-1$, $\delta_{ij}^* = -\sum_{m=j+2}^{q} \delta_{im}$, $j = 1,2, \dots, q-1$.

Parameter α_i is the error-correcting speed of adjustment term, whose sign is expected to be negative if there is a valid error-correction mechanism in the long run for the levels form of the vector of variables in the equation. The error correction term (ECT) in the model represents the speed at which the dependent variables revert to their long-run equilibrium values following a deviation from equilibrium. It provides insights into the adjustment process. Specifically, the vector θ_i', captures the long-run relationships among the variables in the system, which are of particular importance. To estimate the model described in Equation (2), we employ the Pooled Mean Group (PMG) estimator proposed by Pesaran,

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[21] The model described closely follows Blackburne III and Frank (2007) estimation of non-stationary heterogeneous panels model which starts with the derivation of Equation (2) from the standard autoregressive distributed lag (ARDL) specification in the form; $y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}' x_{i,t-j} + \mu_i + \epsilon_{it}$, where the number of groups is $i = 1,2, \dots, N$; the number of periods is $t = 1,2, \dots, T$; x_{it} is a $k \times 1$ vector of explanatory variables; δ_{it} are the $k \times 1$ coefficient vectors; λ_{ij} are scalars, and μ_i is the group specific effect. If the variables in the ARDL model are, for example, I(1) and cointegrated, then the error term is an I(0) process for all i. As stated by Blackburne III and Frank (2007), the principal feature of cointegrated variables is their responsiveness to any deviation from long-run equilibrium. This feature implies an error correction model in which the long-run dynamics of the variables in the system are influenced by the deviation from equilibrium. Hence, it is often re-parameterized as described in equation (2).

Shin, and Smith in (1997) and (1999). This estimator allows for the consideration of both heterogeneous short-run dynamics and common long-run relations in our estimations. By utilizing the PMG approach, we are able to account for variations across individual entities while capturing the collective behavior of the variables over time.

4.3 Data description and sources

This paper utilizes annual data series from 26 countries, collected from various sources such as the World Development Indicator (WDI) of the World Bank, the International Monetary Fund (IMF), the International Financial Statistics (IFS), and the British Petroleum (BP) website. The data covers the time period from 1980 to 2021. To investigate the impacts of the transition towards green energy production on greenflation, the metal-minerals commodity price index[22] from the World Bank commodity price database (Pink Sheet)[23] was used as a proxy for greenflation. For the driving factors of greenflation, the consumption of renewable energy sources, particularly solar and wind energy consumption, was considered as transition variables. These consumption data were retrieved from the BP Statistical Review of World Energy[24]. The data on metal imports and exports, represented as the percentage shares of total merchandise imports and exports, were obtained from the WDI-World Bank. The impact of climate change on greenflation was assessed using temperature change data retrieved from the IMF-Climate database[25]. Global inflation was proxied by the US Producer Price Index (PPI), acquired from the International Financial Statistics (IFS). Additionally, the effect of global productivity[26] was considered using data obtained from Dieppe, Celik, and Kindberg-Hanlon (2020)[27]. By incorporating these various datasets, we aimed to explore the relationships and influences of different factors on the occurrence of greenflation.

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22 The commodities in this sector are considered critical commodities needed for the production of renewable sources of energy (see; IEA 2021; Luke et al., 2022), https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp220317_2~dbb3582f0a.en.html

23 Available at; https://www.worldbank.org/en/research/commodity-markets

24 Available at; https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/commodity-prices.html

25 The indicator is based on climate data from IMF's. The indicator represents annual estimates of mean surface temperature change measured with respect to a baseline climatology. Available at: https://climatedata.imf.org/datasets/4063314923d74187be9596f10d034914/explore

26 Constructed as a simple average of labour productivity (GDP per employment) for the 26 countries analyzed

27 Available from https://www.worldbank.org/en/research/publication/global-productivity

The second part of the paper focuses on examining the relationships between real exchange rates and their fundamental factors.[28] To measure the real exchange rates, data on CPI-based real effective exchange rates (referred to as the real exchange rate) were obtained from the IFS (International Financial Statistics). In order to investigate the potential effects of commodity price developments on real exchange rates and identify potential fossil or renewable currencies, the energy commodity price indices (referred to as the fossil commodity price index) and the metal-minerals commodity price indices (referred to as the renewable energy commodity price index) were retrieved from the World Bank commodity price database. To construct the real values of the fossil and renewable commodity price indices, a methodology similar to that used by Bodart et al. (2012) and Cashin et al. (2004) was followed. The nominal values of the fossil commodity price index were deflated using the World Bank's unit value of manufactured exports (MUV) [29] to calculate their real values.[30] Likewise, the real values of the renewable commodity price index [31] were calculated using an analogous approach.

These real commodity price indices are commonly used as proxies for terms of trade in the commodity-currency literature to mitigate endogeneity issues (as demonstrated in studies by Ricci et al., 2013; Cashin et al., 2004; Bodart et al., 2012). Previous research has also found that the differentials in sectoral labor market productivity (tradable vs. non-tradable) can explain the persistence in real exchange rates even after accounting for the effects of real commodity prices. This phenomenon is known as the Balassa-Samuelson[32] effect (Balassa 1964 and Samuelson 1964), and its influence has been examined in studies by Ricci et al. (2013), Jaunky (2008), and Chen and Rogoff (2003).

Hence, to control for the Balassa–Samuelson effect in our study, we constructed sectoral productivity differential [33] (hereafter productivity differential) as the log of relative productivity between tradable and non-tradeable sectors using the US sectoral productivity as the benchmark, so it is

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28 Economic theory suggests that the variations in the long-run (equilibrium) movements in real exchange rate are determined by the long-run values of its fundamentals, such as the terms of trade, productivity differentials, and the interest rate differential, see e.g; Kapfhammer et al., (2020), Cashin et al., (2004), Habib and Kalamova (2007), Froot and Rogoff (1995), Balassa (1964) and Samuelson (1964).

29 The MUV index as a deflator is by far the most commonly used in previous studies related to the commodity-currencies (see e,g Habib and Kalamova 2007; Cashin et al. 2004; Cashin et al., 2000; Aslam et al., 2016)

30 The index comprises of nominal prices of crude oil, gas and coal (annual)

31 The index comprises of nominal prices of renewable (metal and minerals) commodities such as aluminium, copper, nickel, iron ore, tin and zinc

32 The Balassa–Samuelson assumption posits that the productivity differential between tradable and non-tradable sectors runs the prices of tradeable (p_t^T, p_t^{T*}) and non-tradeable goods (p_t^{NT}, p_t^{NT*}) affecting the the real exchange (q_t) determination as follows: $q_t = (s_t + p_t^T - p_t^{T*}) - \alpha[(p_t^{NT} - p_t^T) - (p_t^{NT*} - p_t^{T*})]$. Assuming the term $(s_t + p_t^T - p_t^{T*})$ is constant, then the final equation can be expressed in term of productivity as $q_t = -\alpha[(a_t^{NT} - a_t^T) - (a_t^{NT*} - a_t^{T*})]$. For the details of the derivation and notations see e.g., Peltonen and Sager (2009), Jaunky (2008) Sjöö (2002), Balassa (1964) and Samuelson (1964).

33 We constructed the productivity level indicators for both the tradable and non-tradable sectors for each country, and then calculated the overall productivity differential for each country using the US as the benchmark.

defined as $A_{it} = (A_T^* - A_N^*)_{US} - (A_T - A_N)_i$, where A_{it} denotes the log of productivity differential for country i in period t. The expression $(A_T^* - A_N^*)_{US}$ stands for the log of labor productivity differential between tradable[34] and non-tradable sector in the foreign country (US), and $(A_T - A_N)_i$ represents the log of productivity differential between the tradable and non-tradable sector in the home country (see e.g., Ricci et al. 2013; Peltonen and Sager 2009; Jaunky 2008; Chen and Rogoff 2003 for an analogous approach). In accordance with the original ideas of Balassa (1964) and Samuelson (1964), the productivity differential is expected to have a positive effect on the real exchange rate. The data on sectoral labor productivity are retrieved from the WDI-World Bank

Another fundamental related to the deviations of real exchange rate from Purchasing Power Parity (PPP) is the real interest rate differential (Kapfhammer et al. 2020; Habib and Kalamova 2007). Real interest rate differential for the home country is constructed by taking the difference between the real interest rate of the home country and the real interest rate of the foreign country (US as a benchmark); $rd_{it} = r_i - r_{US}^*$, where rd_{it} is the real interest rate differential, r_i and r_{US}^* is the real interest rate for the home and foreign country, respectively (see e.g., Kapfhammer et al., 2020). The data are retrieved from the WDI-World Bank. In sum, the set of 26 countries analysed comprises of 18 advanced countries and 8 emerging countries: all shown in Table 1. All the variables are log transformed, and the detailed descriptions are given in the Appendix Table A.2.

[34] Traded sectors include agriculture, forestry, mining, manufacturing etc., and non-tradable sector comprises of services such as utilities, transport services and storage, communications, finance and insurance, and cultural and recreational services, etc.

Table 1. List of Countries

Advanced economies		Emerging economies	
Europe	**Other regions**	**Africa**	**Asia**
Austria	Australia	South Africa	China
Belgium	Canada		Malaysia
Finland	Japan	Middle East	Philippines
France	New Zealand	Saudi Arabia	
Germany	Singapore		
Italy	USA	Latin America	
Netherlands	UK	Brazil	
Spain		Chile	
Norway		Mexico	
Sweden			
Switzerland			

4.4 Empirical results and discussions

4.4.1 Order of integration (unit root analysis)

Our empirical analysis begins by scrutinizing the data generation processes of the time series. We assess whether the analyzed time series exhibit non-stationarity, indicating if the series follows a unit root (I(1)) process, or if they are stationary (I(0)) processes. To accomplish this, we employ the Phillips and Perron (1988) test (referred to as PP test) and the Kwiatkowski, Phillips, Schmidt, Shin (1992) test (referred to as KPSS test) for unit root analysis. The PP test evaluates the null hypothesis that the series possesses a unit root (I(1)), while the alternative hypothesis suggests stationarity (I(0)). Conversely, the KPSS test assumes the null hypothesis of stationarity (I(0)), with the alternative hypothesis indicating non-stationarity (I(1). The inclusion of the KPSS test acts as a robustness check for our analysis. To ensure the test equation provides non-autocorrelated and heteroscedasticity consistent error terms, we utilized the Bartlett kernel, incorporating Andrews' (1991) automatic bandwidth selector, and the prewhitened kernel estimator developed by Andrews and Monahan (1992).

Table 2a. Unit root results based on Phillips and Perron (1988) test.

	Phillips–Perron (PP) z(t) test - $H_{0:}$ x ~ I(1) (*The Dickey-Fuller critical value for H_0 at 5% in is -3.53)*								
Panel 1 Countries	Rer	Fossil	Renew	REC	Metal imports	PPI	Prod. Diff	RIR Diff	N-W lags
Australia	-2.03	-2.14	-2.99	-8.24	-4.21	-2.42	-2.32	-3.16	3
Austria	-2.26	-2.14	-2.99	-1.53	-2.36	-2.53	-1.91	-2.72	3
Belgium	-2.03	-2.14	2.99	-0.72	-2.85	-1.44	-2.53	-6.02	3
Brazil	-2.33	-2.14	-2.99	-1.73	-2.99	-7.41	-0.74	-2.65	3
Canada	-2.03	-2.14	-2.99	-0.92	-3.51	-0.79	-0.29	-3.22	3
Chile	-2.20	-2.14	-2.99	-7.11	-3.39	-2.46	-1.20	-	3
China	-2.20	-2.14	-2.99	-9.50	-2.41	-1.72	-1.10	-4.08	3
Finland	-2.75	-2.14	-2.99	-2.11	-3.00	-3.15	-1.61	-2.78	3
France	-3.32	-2.14	-2.99	-0.64	-4.23	-2.39	-1.52	-2.36	3
Germany	-2.54	-2.14	-2.99	-1.24	-2.76	-2.74	-1.43	-4.53	3
Italy	-2.52	-2.14	-2.99	-1.38	-4.40	-0.01	-1.39	-2.96	3
Japan	-2.02	-2.14	-2.99	-2.41	-1.40	-1.25	-1.90	-2.82	3
Malaysia	-2.19	-2.14	-2.99	-2.66	-2.42	-0.59	-1.03	-3.01	3
Mexico	-2.82	-2.14	-2.99	-2.22	-3.29	-1.05	-0.42	-3.85	3
Netherlands	-3.08	-2.14	-2.99	-2.79	-3.63	-1.93	-0.25	-3.09	3
Norway	-2.18	-2.14	-2.99	-7.30	-2.45	-1.33	-0.31	-3.14	3
New Zealand	-3.03	-2.14	-2.99	-1.57	-4.01	-2.59	-0.98	-3.29	3
Philippines	-2.08	-2.14	-2.99	-2.82	-3.88	-0.10	-0.24	-3.80	3
Singapore	-2.39	-2.14	-2.99	-2.12	-2.57	-	-2.00	-4.10	3
South Africa	-3.19	-2.14	-2.99	-0.78	-4.06	-1.53	-0.51	-3.01	3
Spain	-2.54	-2.14	-2.99	-1.25	-2.34	3.43	-0.54	-3.49	3
Saudi Arabia	-1.33	--2.14	-2.99	-1.80	-1.77	-	-2.25	-7.47	3
Sweden	-3.15	-2.14	-2.99	-2.44	-3.28	-3.44	-1.56	-3.25	3
Switzerland	-2.96	-2.14	-2.99	-2.37	-4.44	-1.91	-2.62	-3.17	3
UK	-2.45	-2.14	-2.99	-0.02	-2.89	-2.38	-1.93	-3.06	3
USA	-2.53	-2.14	-2.99	-2.78	-3.14	-1.84	-	-	3

Panel 2			Global variables						
	GF	REC	SEC	WEC	MP	CD	ME	GP	PPI
	-2.77	-3.29	-4.07	-1.79	-2.30	-5.67	-3.18	-1.79	-1.85

Note: The table reports the test statistics of Phillips–Perron (1988) unit root estimations. The unit root test includes the constant and trend terms in the regression. The **bold values** indicate rejection of the null hypothesis at 5% significance level (i.e., critical value for rejection of the H_0 at 5% is -3.53). The lag structure for the test equation is estimated based on the Newey-West (N-W) procedure. Rer denote real exchange rate; calculated as a geometric weighted average of bilateral real exchange rates between home country and its trade partners. Renew denote renewable commodity price index, REC is renewable energy consumption, PPI is producer price index, and lastly Prod. Diff and RIR Diff represent productivity and real interest rate differentials respectively. For the global variables, GF denote greenflation, SEC and WEC represent solar and wind energy consumption respectively, MP is metal imports, CD is the climate change indicator and ME stands for metal exports and GP is global productivity.

Table 2b. Unit root results based on Kwiatkowski, Phillips, Schmidt, Shin (1992) test.

KPSS test - H0: x ~ I(0) (Critical value for H0 at 5% is 0.15)									
Countries	Rer	Fossil	Renew	REC	Metal imports	PPI	Prod. Diff	RIR Diff	lags
Australia	0.18	0.16	0.17	0.26	0.20	0.07	0.11	0.17	3
Austria	0.15	0.16	0.17	0.26	0.19	0.15	0.17	0.07	3
Belgium	0.18	0.16	0.17	0.28	0.16	0.21	0.24	0.05	3
Brazil	0.16	0.16	0.17	0.26	0.06	0.15	0.19	0.17	3
Canada	0.17	0.16	0.17	0.25	0.19	0.16	0.29	0.07	3
Chile	0.18	0.16	0.17	0.24	0.09	0.11	0.17	-	3
China	0.25	0.16	0.17	0.24	0.17	0.11	0.19	0.08	3
Finland	0.18	0.16	0.17	0.10	0.16	0.17	0.31	0.16	3
France	0.17	0.16	0.17	0.28	0.16	0.18	0.16	0.17	3
Germany	0.15	0.16	0.17	0.29	0.20	0.16	0.19	0.07	3
Italy	0.26	0.16	0.17	0.26	0.19	0.20	0.19	0.20	3
Japan	0.24	0.16	0.17	0.24	0.19	0.16	0.16	0.10	3
Malaysia	0.18	0.16	0.17	0.26	0.22	0.17	0.18	0.16	3
Mexico	0.16	0.16	0.17	0.20	0.19	0.17	0.19	0.09	3
Netherlands	0.17	0.16	0.17	0.25	0.18	0.19	0.18	0.17	3
Norway	0.21	0.16	0.17	0.23	0.16	0.22	0.28	0.19	3
New Zealand	0.17	0.16	0.17	0.24	0.09	0.18	0.16	0.16	3
Philippines	0.16	0.16	0.17	0.15	0.21	0.20	0.22	0.15	3
Singapore	0.17	0.16	0.17	0.20	0.16	-	0.19	0.04	3
South Africa	0.16	0.16	0.17	0.21	0.17	0.19	0.23	0.17	3
Spain	0.17	0.16	0.17	0.26	0.23	0.17	0.18	0.18	3
Saudi Arabia	0.21	0.16	0.17	0.22	0.18	-	0.16	0.06	3
Sweden	0.18	0.16	0.17	0.29	0.19	0.16	0.23	0.17	3
Switzerland	0.18	0.16	0.17	0.25	0.15	0.18	0.18	0.07	3
UK	0.16	0.16	0.17	0.26	023	0.17	0.23	0.22	3
USA	0.18	0.16	0.17	0.28	0.22	0.21	-	-	3

Note: The table reports the test statistics of Kwiatkowski et al., (1992) for the null hypothesis of stationarity in the series. The unit root test includes the constant and trend terms in the regression. The bold values indicate rejection of the null hypothesis at 5% significance level (i.e., critical value for rejection of the H_0 at 5% risk level is 0.15*)*. For the notations see Table 1a.

The estimates presented in Table 2a indicate that out of the 203 PP unit root tests conducted, only 18 tests reject the null hypothesis of a unit root, providing evidence in favor of stationarity. Specifically, the unit root in renewable energy consumption (REC) is rejected for Australia, Chile, China, and Norway. For the metal imports time series, no evidence of a unit root is found for countries such as Australia, Italy, Netherlands, and the Philippines. The Producer Price Index (PPI) remains stable for Brazil. Similarly, the real interest rate differential is also stable for countries including Belgium, China, Germany, the Philippines, Singapore, and Saudi Arabia. Overall, the majority of the series display non-stationarity.

Table 2b reports the results of the KPSS-test with the null hypothesis of stationary series (I(0)). In most cases where the PP test rejects the null hypothesis, the KPSS test does not support the notion of stationarity. Across the 203 KPSS unit root tests conducted; 185 tests indicate rejection of the null hypothesis of stationarity. Therefore, considering the results of both tests, it can be inferred that the variables are mostly non-stationary processes in levels (I(1)), but they exhibit stationarity in first differences (I(0))[35].

4.4.2 Greenflation: The global impact

The following section aims to investigate the impact of the transition towards sustainable energy production on global greenflation. This analysis considers global demand and supply models, which capture both the direct and indirect effects of the transition on greenflation. Equation 1 is utilized as the basis for this examination. Specifically, the focus is on assessing whether energy transition variables[36] such as global renewables energy consumption, global solar energy consumption, and global wind energy consumption, play a role in driving greenflation. The expectation is that as the metals and minerals sector products serve as crucial inputs for renewable energy production, any price fluctuations in this sector will directly impact market prices. This perspective is supported by research conducted by Borg et al. (2022), Li et al. (2020), and Fizaine and Court (2015).

Therefore, it is predicted that an increase in the transition variables will directly lead to a rise in demand for renewable energy production inputs. Consequently, this will indirectly influence greenflation. In other words, the expectation is that the energy transition variables will have a positive explanatory power in terms of the development of greenflation. To investigate the direct effect, the role of global metal imports is examined by measuring it as the percentage share of total merchandise imports. It is expected that an increase in metal imports will directly impact global prices for metals and minerals commodities. Another demand factor taken into consideration is the impact of global productivity on greenflation.

Table 3 presents the regression estimates of the global demand model from Model 1. It is indeed encouraging to observe that changes in greenflation are positively and significantly associated with changes in the three global demand

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35 The results for the first differenced values of the time series are available upon request

36 We define the energy transition variables as indicators for renewable energy alternative to fossil energy. The production use and storage of renewable energy sources such as solar, wind power, electric cars and other renewable technologies rely on critical metal and minerals primary commodities such as copper, lithium, nickel, cobalt, precious metals, etc. as the main inputs for production (IEA 2021; Zhu et al., 2022; Borg et al., 2022).

variables, namely renewables energy consumption, solar energy consumption, and metal imports. These findings align with our expectations and suggest that greenflation is influenced by these key global energy demand factors.

With a coefficient of determination (R-squared) value indicating that the model explains approximately 76% of the variation in greenflation, it demonstrates that the rising prices of global metal and minerals commodities can be attributed to the three main global energy demand variables. It is noteworthy to mention that the increase in renewable energy consumption leads to higher demand for renewable energy production inputs in the short to medium term, which can significantly drive up prices. This finding is consistent with the analysis provided by the IEA (2021) energy market outlook, which highlights that the accelerating transition to renewables is expected to contribute to upward price pressure on key energy transition-related commodities like copper, aluminium, nickel, uranium, and precious metals worldwide.

Table 3. Empirical results for the analysis of greenflation determinants: Global effects

Dependent variable: Greenflation					
Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
Renewables consumption	0.115*	0.116*	0.117*	0.036	0.013*
	(0.06)	(0.06)	(0.06)	(0.07)	(0.01)
Solar energy consumption	0.141**	0.144**	0.145**	0.063	
	(0.07)	(0.07)	(0.07)	(0.07)	
Wind energy consumption	-0.150	-0.149	-0.150	-0.058	
	(0.12)	(0.12)	(0.12)	(0.12)	
Metals imports	0.469***	0.471***	0.460***	0.429***	0.421***
	(0.04)	(0.04)	(0.05)	(0.05)	(0.03)
Global productivity	0.816	0.884	0.868	0.872	
	(0.88)	(0.94)	(0.96)	(1.04)	
Climate change indicator		0.072**	0.077**	0.007	0.074**
		(0.02)	(0.03)	(0.07)	(0.035)
Metals exports			0.014	0.016	
			(0.04)	(0.04)	
Global inflation (PPI)				0.011**	0.012***
				(0.00)	(0.00)

Dependent variable: Greenflation					
Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	0.020	0.021	0.022	0.012	0.015
	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)
R2	0.761	0.769	0.766	0.777	0.798
Number of observations	41	41	41	41	41
BIC	-52.9	-49.6	-46.4	-44.6	-58.6

Note: This table reports the parameter estimates of Equation (1) with robust standard errors in parenthesis. *, **, and *** denotes the 10, 5, and 1% significance levels, respectively.

Interestingly, the global productivity factor, measured as the simple average of labor productivity (GDP per employment) for the 26 countries analyzed, does not exhibit statistical significance in relation to greenflation at the aggregate level. This finding strengthens the evidence supporting the market outlook's assertion concerning the role of renewable energy consumption and the demand for renewable energy production inputs (metal and minerals imports) in driving greenflation. Both variables demonstrate positive and statistically significant impacts on greenflation.

Even though the demand chain factors, such as transitional variables and metal imports, can be considered as the key determinants of greenflation development according to our estimates, we believe that the recent surge in metal and mineral prices may also be influenced by supply chain and environmental factors. To account for these additional factors, we expanded Equation 1 to include the direct effects of the supply chain and an indirect effect of the environment. For the environmental effect, we incorporated the climate change indicator since studies have shown that an increase in this indicator leads to higher green investments (Li et al., 2021) and a sense of urgency for transitioning to a greener economy with renewable energy sources (Luke et al., 2022). Thus, we anticipate a positive impact of climate change on greenflation. As for the supply chain factors, we considered global metals exports and used the US PPI-Producer Price Index as a proxy for global inflation. By including these variables, we aim to capture the influence of supply chain dynamics on the development of greenflation.

We expect that global inflation will have a direct positive impact on greenflation as well. The estimates for the augmented Equation (1) are reported in Models 2-5 in Table 3 above. The results demonstrate that the climate change indicator is a vital factor in driving greenflation at the global level. As per our expectations, the variables enter Models 2, 3, and 5 with the correct sign that we assumed beforehand, and they show economically significant estimates at a 5% confidence level, respectively. However, the parameter estimates for metal exports %-share of total merchandise exports in Models 3 and 4 are statistically insignificant, despite entering with the expected sign. Moreover, we find that changes in the US-PPI (global inflation) can be considered as an important determinant in driving greenflation. The change in US-PPI enters Models 4 and 5 with the correct sign and statistically significant parameter estimates.

At this stage, the estimates presented in Table 3 for Model 5 indicate that two demand-side factors, namely global renewable energy consumption and global metals imports, are crucial determinants of greenflation worldwide. Furthermore, the results demonstrate that global inflation and the climate change factor also significantly contribute to driving greenflation. These important factors account for approximately 80% of the variations in greenflation. In summary, the evidence suggests that the global commodity demand-chain side effects, characterized by the rise in global renewable energy consumption and the importation of metals and minerals for renewable energy production, are the primary drivers of greenflation at the global level (as also noted by Luke et al., 2022). Conversely, the results presented in Table 3 provide valuable insights into the relationship between energy transition variables, global demand factors, and greenflation, highlighting the importance of renewable energy consumption and its associated demand for production inputs in influencing the prices of metals and minerals commodities.

To expand this analysis to the regional level, we initially examined the correlation among the variables in the equation. Based on the correlation matrix presented in Table 4 below, we observe a strong positive correlation between renewables energy consumption and the consumption levels of solar and wind energy, as anticipated (see column 1). It is worth noting that solar energy and wind energy consumption are subcomponents of overall renewable energy consumption. Additionally, we find a high correlation between metal export and import (column 4, row 6). Consequently, to avoid multicollinearity with other factors, we have excluded these variables, namely solar energy, wind energy consumption, and metal export, from the regression model. Furthermore, when these variables were excluded from the estimation of Model 5 in Table 3, the results remained statistically unchanged.

Table 4. Pairwise correlation matrix for the independent variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Renewables consumption	1.000							
(2) Solar energy consumption	0.953	1.000						
(3) Wind energy consumption	0.998	0.963	1.000					
(4) Metals imports	0.468	0.416	0.470	1.000				
(5) Climate indicator	0.600	0.670	0.776	0.302	1.000			
(6) Metals exports	0.146	0.170	0.166	0.950	-0.076	1.000		
(7) Global inflation (US PPI)	0.576	0.705	0.851	0.474	0.883	0.042	1.000	
(8) Productivity	0.654	0.456	0.613	0.198	0.875	-0.221	0.900	1.000

Note: This table reports the pairwise correlation matrix of the independent variables in the Equation (1)

4.4.2.1.1 Greenflation: Regional impacts

In order to conduct a comprehensive analysis, we examined a panel of Advanced and Emerging countries to assess the impact of transitioning towards sustainable energy production on greenflation. To accomplish this, we made modifications to the demand and supply sides of Equation 1 in our model, enabling us to capture the regional direct and indirect effects on greenflation represented as

$$\Delta gf_t = \alpha_i + \gamma_1 \Delta rec_{it} + \gamma_2 \Delta mp_{it} + \gamma_3 \Delta fl_{it} + \gamma_4 \Delta p_{it} + \gamma_5 \Delta x_{it} + \epsilon_t, \quad (3)$$

where gf_t denotes greenflation at time t, rec_{it} represents country specific renewables energy consumption at time t, mp_{it} denotes country specific metals imports as %-share of total merchandise imports at time t, p_{it} denotes country-specific productivity at time t, fl_{it} denotes inflation proxy based on the country specific producer price indexes at time t, and lastly, x_{it} denotes country specific climate change indicator at time t, γ_i denotes the parameter estimates on the respective variables and the notation Δ denotes the log differenced values of the variables. We modelled $\alpha_i = \gamma_0 + \gamma_1 Z_i$ to capture the country fixed effects. Where Z_i controls for the unobserved time-invariant heterogeneity across the countries in the panel. Finally, ϵ_t is the innovation expected to be iid (0, Σ). Considering that in the panel data we have T > N, and the Hausman test supported the Fixed Effects over Random Effects model, we estimated the model (Equation 3) using the Panel Fixed Effect estimator.

Table 5 below displays the regression results for Equation 3, categorized into Models 1-3. Panel A pertains to Advanced countries, while Panel B focuses on Emerging countries. Model 1 incorporates control variables for three major factors driving greenflation, namely renewable energy consumption, metal imports, and inflation. Models 2 and 3 encompass additional factors that have been identified as relevant on a global scale for driving greenflation. In general, the regression estimates demonstrate that the regional effects align with the global effect. However, certain discrepancies in the results between the regions are also evident.

Certainly, based on the regional analysis, it appears that both renewable energy consumption and metal imports have a unanimous effect on greenflation. This aligns with the global estimates, which also identify these factors as significant drivers of greenflation. Importantly, these main demand factors, namely renewable energy consumption and metal imports, consistently show the expected sign and statistical significance across all three models for both Advanced and Emerging countries. Furthermore, the inflation variable consistently exhibits the expected sign and statistical significance in all three models for Advanced countries. This suggests that inflation rates in Advanced countries are more influential in driving greenflation compared to Emerging countries. Although global inflation is found to be a significant driver, the results indicate that inflation rates specific to Advanced countries have a greater impact on greenflation development. In contrast, the evidence suggests that inflation in Emerging countries is not as important a contributing factor to greenflation.

In line with our previous findings, Table 5 Model 3 confirms that the climate change variable displays a positive sign and exhibits a significant association with greenflation in both the Advanced and Emerging country groups. This result indicates that regional efforts to address climate change through transitioning to sustainable energy production contribute to the increasing prices of metal-mineral commodities required for green energy production. This outcome aligns with our initial expectations. Additionally, Model 2 demonstrates that the regional productivity estimate enters with positive and significant parameter estimates for both the advanced and emerging country groups. In contrast to the global effect, the disaggregated productivity data suggest that sector-specific productivity is a significant contributing factor to the rising prices of metal-mineral commodities needed for green energy production. This finding is not limited to the green energy sector alone but encompasses other related sectors as well. It is worth noting that the overall sectoral productivity in both the advanced and emerging countries drives the growing demand for commodities necessary for production, supporting our initial expectations.

Overall, the results consistently indicate that the increasing demand for renewable energy consumption, metal-mineral commodity imports, productivity, and inflation are driving the rising prices of metal-mineral commodities required for green energy production. These findings are consistent both at the global and regional estimates. Furthermore, we have also examined the individual country-level effects and added them to Appendix A.1 for further securitization. In general, our results reveal that the country-specific demand for metal-mineral commodity imports is the primary contributing factor to global greenflation. However, the specific factors of renewable energy consumption and inflation play a minor role in influencing global greenflation. It is essential to note that the aggregated level data have a significant impact on driving greenflation, which is expected. To summarize, our findings strongly support Isabel Schnabel's (2022)[37] message in her recent speech regarding climate conditions and the factors contributing to the increasing prices of metal-mineral commodities, as well as the global inflation crises. In line with the recent development of greenflation, our research demonstrates clear interconnections among these factors at the regional and global levels.

[37] https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp220317_2~dbb3582f0a.en.html

Table 5. Empirical results for the analysis of greenflation determinants: Regional effects

Dependent variable: Greenflation			
Panel A: Advanced countries	Model (1)	Model (2)	Model (3)
Renewables consumption	0.0704*	0.0735**	0.0579*
	(0.0488)	(0.0327)	(0.0374)
Metals imports	0.171***	0.169***	0.167***
	(0.0272)	(0.0275)	(0.0273)
Inflation (PPI)	0.00313**	0.00311**	0.0032**
	(0.0013)	(0.0014)	(0.0014)
Productivity		0.685*	0.600
		(0.310)	(0.375)
Climate change indicator			0.0174**
			(0.0065)
Constant	0.0256***	0.0190***	0.00348
	(0.00376)	(0.00527)	(0.0074)
Country FE	Yes	Yes	Yes
Observations	738	738	738

Panel B: Emerging countries	Model (1)	Model (2)	Model (3)
Renewables consumption	0.0535***	0.0742***	0.0530**
	(0.0101)	(0.0163)	(0.0221)
Metals imports	0.0765**	0.0734**	0.0735**
	(0.0259)	(0.0262)	(0.0266)
Inflation (PPI)	0.00128	0.00126	0.00128
	(0.0008)	(0.0008)	(0.0007)
Productivity		0.634*	0.528
		(0.331)	(0.336)
Climate change indicator			0.031**
			(0.0104)
Constant	0.0152***	0.00536	-0.0138
	(0.00176)	(0.00510)	(0.00799)
Country FE	Yes	Yes	Yes
Observations	328	328	328

Note: This table reports the parameter estimates of Equation 5. The robust standard errors are reported in parenthesis. *, **, and *** denote the 10, 5, and 1% significance levels, respectively.

4.4.3 Fossil and renewable currencies (FC and RC)

In this section, we focus on examining the long- and short-run impacts of economic fundamentals on the development of the real exchange rate. Our first step is to test the data generation processes of the variables and determine if there is a homogeneous cointegration relationship among them. Assuming we establish that the data generation processes follow a unit root, or in other words, they are I (1) processes, we will proceed to investigate the long-run panel cointegrating relationships between the real exchange rate and its fundamentals. These fundamentals include the real commodity price (both fossil and renewable), productivity differential, and real interest rate differential for the respective groups.

4.4.3.1 Order of integration (Unit root test)

The panel unit root test results are reported in Table 6 for the full sample, and for the subsamples of advanced and emerging countries, respectively. Utilizing the Im-Pesaran-Shin (IPS hereafter) (2003) unit root method, we analysed the null hypothesis that all the panels contain a unit root. Alternatively, we also employed the Levin-Lin-Chu (LLC hereafter) (2002)- test to analyze the null hypothesis that the panels contain a unit root. This serves as a robustness check. Each test is based on the null hypothesis that the panel data contains unit root, against the alternative hypothesis that the panel data are stationary. On one hand, the IPS test assumes that the slope of the analyzed observations in the time-series dimension is heterogenous among the cross-sectional observations, whereas the LLC test considers the slope of the panel as homogenous over the cross-section. From the observed results, it can be noted that the estimates presented in Table 6 demonstrate that both the real exchange rate and real interest rate differentials exhibit stationarity at the level of observations. These estimates remain consistent when considering the IPS and LLC tests. On the other hand, the remaining variables, namely the fossil commodity index, renewable (metal-mineral) commodity index, and productivity differentials, show an integration order of 1, indicating that they are stationary when considering first differences. Notably, these estimates remain consistent when analyzing both the full dataset and sub-samples. With the understanding that our panel consists of both I(1) and I(0) data series, we proceed to investigate the long-run cointegration relationships between the real exchange rate and its underlying fundamentals, which serve as the independent variables.

4.4.3.2 Cointegration analysis

Economic theory[38] suggests that if two or more variables, such as the real exchange rate and its fundamentals, are non-stationary (following I(1) processes),

[38] See e.g.., Chen and Rogoff (2003), Engle and Granger (1987), Pesaran, Shin and Smith. (2001)

there is a possibility (although not always guaranteed) that they may be cointegrated. This means that they could share a common linear, stable, and long-run relationship. In order to explore this assumption, we conducted a cointegration test. Before proceeding with the cointegration test, we performed a pairwise correlation analysis to ensure the validity of the variables included in the panel and to avoid multicollinearity issues. The estimates presented in Table 7 indicate that the correlations between the variables in the panel are very low, which is satisfactory. This suggests that all the variables can be included in further analysis without concerns about significant multicollinearity.

Table 6. Panel unit root test results

	IPS		LLC	
Full sample	Levels	First Diff	Levels	First Diff
Real exchange rate	-5.8225***		-12.0004***	
Fossil commodity index	1.2738	-19.5270***	1.0923	-14.1064***
Renewable commodity index	-1.2690	-23.4398***	-1.8430**	-20.5354***
Productivity Differential	3.2289	-16.2129***	3.2382	-15.5809***
Real Interest Rate Differential	-11.0005***		-10.5320***	
Advanced Countries				
Real exchange rate	-4.1820***		-4.7640***	
Fossil commodity index	1.0504	-16.1024***	0.9007	-11.6324***
Renewable commodity index	-1.0464	-19.3290***	-1.5198	-16.9339***
Productivity Differential	1.7793	-13.5826***	1.2694	-13.0650***
Real Interest Rate Differential	-8.4034***		-8.2344***	
Emerging Countries				
Real exchange rate	-4.1966***		-5.0069***	
Fossil commodity index	0.7206	-11.0462***	0.6179	-7.9798***
Renewable commodity index	-0.7179	-13.2596***	-1.0426	-11.6166***
Productivity Differential	3.1142	-8.8607***	5.5153	-8.4937***
Real Interest Rate Differential	-7.1963***		-6.5785***	

Note: The table reports the t- statistics of the Im-Pesaran-Shin (2003) and Levin-Lin-Chu (2002) unit root test for the full sample, advanced, and emerging countries. The *, ** and *** notations denote 10, 5 and 1 percent significance level respectively. Diff denotes differenced values.

To investigate whether the real exchange rates and its fundamentals share a common stochastic trend, we utilized the Kao (1999) and Pedroni (1999, 2004) tests. These tests allow us to examine the equilibrium cointegration relationship between the real exchange rate and its fundamentals. We first conducted a cointegration test for the real exchange rate and all the supposed fundamentals included in the vector of variables of interest. Additionally, we examined the pairwise cointegration between the real exchange rate and specific fundamentals, such as real commodity prices, productivity differentials, and real interest rate differentials. These pairwise tests help us explore the potential cointegration relationships between the real exchange rate and each individual fundamental separately. Both the Kao and Pedroni tests assume the null hypothesis of no cointegration against the alternative hypothesis that all panels are cointegrated. By conducting these tests and comparing their results, we can assess the robustness of our findings.

Table 7. Pairwise correlations between the real exchange rate and its main determinants

Variables	(1)	(2)	(3)	(4)	(5)
(1) Real exchange rate	1.000				
(2) Renewable commodity index	-0.116	1.000			
(3) Fossil commodity index	-0.055	0.745	1.000		
(4) Productivity Differential	0.103	-0.040	-0.014	1.000	
(5) Real Interest Rate Differential	0.148	0.101	0.111	-0.048	1.000

Table 8. Panel cointegration test results for the dependence of real exchange rate on its main determinants

Cointegration	Kao	Pedroni
Advanced Countries (18 countries)	ADF t test	PP t test
Real exchange rate ~ All	-4.6710***	-0.5087
Real exchange rate ~ Fossil commodity index	-5.1524***	-2.8155***
Real exchange rate ~ Renewable commodity index	-3.5467***	-3.4884***
Real exchange rate ~ Productivity Differential	-4.2199***	-2.4725***
Real exchange rate ~ Real Interest Rate Differential	-4.5714***	-2.4384***
Emerging Countries (8 countries)		
Real exchange rate ~ All	-3.5641***	1.1456
Real exchange rate ~ Fossil commodity index	-4.3996***	-1.4041**
Real exchange rate ~ Renewable commodity index	-4.1890***	-2.2935**
Real exchange rate ~ Productivity Differential	-4.1856***	-2.8505***
Real exchange rate ~ Real Interest Rate Differential	-3.6416***	-3.0922***

Note: The table reports the t- statistics of the Kao (1999) and Pedroni (1999, 2004) panel cointegration test for the advanced and emerging countries. The *, ** and *** notations represents 10, 5 and 1 percent significance levels, respectively.

The panel cointegration estimates presented in Table 8 indicate that, in both advanced and emerging countries, the Kao cointegration test rejects the null hypothesis of no cointegration, even at a 1% statistical significance level. This suggests that there is at least one cointegrating vector in the panel, implying a common stochastic trend between the real exchange rates and at least one of its fundamental variables. In contrast, the Pedroni (1999, 2004) cointegration test does not reject the null hypothesis of no cointegration when all the real exchange rate and fundamental variables are included in the model. However, when examining the real exchange rate and individual fundamentals separately, the null hypothesis is rejected, showing cointegration at both 1% and 5% statistical significance levels. These results support the notion of cointegration between the real exchange rate and specific individual fundamentals, which aligns with the findings of the Kao cointegration test. Moreover, the consistency of these test results is observed in both advanced and emerging countries.

4.4.3.3 Long run elasticity and short-run impacts

This section discusses the values for the long-run elasticity parameters and the short-run impacts of the real exchange rates and its fundamentals. The Panel ARDL (1,1) model, specified in Equation (2) is utilized to analyze these relationships. The panel regression estimates for different country groupings, including advanced economies, emerging economies, commodity exporters[39], and commodity importers, are presented in Table 9 (columns 1-4). The results indicate that the error correction term (ECT) appears in all the models with the correct sign (negative) and is statistically significant either at the 1% and 5% levels for all the country groups. This suggests that a long-run equilibrium relationship exists between the real exchange rate and the fundamentals included in the model. Furthermore, it can be inferred that the real exchange rate has a common linear, stable, and long-run relationship with some or all of its fundamentals in the model.

The negative error correction parameter holds significant importance as it indicates the speed at which the real exchange rate returns to its long-run equilibrium value following a shock. For all the groups analyzed, it was observed that when the real exchange rate deviates from its equilibrium value, it tends to rapidly revert back to the long-run equilibrium. In the case of advanced economies, the error correction parameter value of -0.13 suggests that 13% of the deviation from the long-run equilibrium is corrected within one year. This implies that it takes approximately 4 years for the shock to completely disappear, indicating a half-life[40] of the deviation. Similar patterns were observed for commodity importers, with an error correction parameter of approximately -0.13. This means that 13% of the deviation is corrected within one year, resulting in a half-life of around 4 years for the shock to fully disappear.

Emerging economies exhibited an error correction parameter value of -0.10, indicating that 10% of the deviation from the long-run equilibrium is corrected within one year. Consequently, it takes roughly 3 years for the shocks to completely vanish, representing a half-life of the deviation. For commodity exporters, the error correction parameter value is -0.09, implying that 9% of the deviation from the long-run equilibrium is corrected within one year. This suggests a half-life of approximately 3 years for the shocks to fully disappear. Overall, these findings highlight the speed at which the real exchange rate returns to its long-run equilibrium value after a shock, with advanced economies and commodity importers exhibiting a slightly slower adjustment compared to emerging economies and commodity exporters.

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[39] The group of commodity exporter countries includes Australia, Brazil, Canada, Saudi Arabia, Chile, Norway and South Africa, based on UNCTAD (2019) State of commodity dependence publication. The rest of the 19 countries are categorised as commodity importers.
[40]The half-life is the period of time it takes for a unit deviation (shock) to dissolve by half, which can be calculated as: $\log(1/2)/\log(1-|\alpha|)$, where α is the error correction coefficient (see e.g., Ricci et al., 2013; Habib and Kalamova 2007; Cashin et al., 2004)

Table 9. Panel error correction model results

	1	2	3	4
Dependent variable: Real exchange rate	Advanced Economies (18 countries)	Emerging Economies (8 countries)	Commodity Exporters (7 countries)	Commodity Importers (19 countries)
Error correction term (ECT)	-0.131*** (0.019)	-0.099*** (0.022)	-0.086** (0.025)	-0.129*** (0.017)
Long run relations				
Fossil commodity price index	0.092** (0.047)	-0.106 (0.171)	0.204** (0.086)	-0.052 (0.054)
Renewable commodity price index	0.121 (0.082)	0.358 (0.351)	0.507 (0.370)	0.069 (0.099)
Productivity Differential	0.059 (0.169)	0.111 (0.109)	0.157 (0.228)	0.114** (0.057)
Real Interest Rate Differential	-0.010** (0.005)	0.006 (0.006)	0.012 (0.016)	0.004 (0.003)
Short run effects				
Diff Fossil commodity index	0.021*** (0.008)	0.085*** (0.022)	0.089*** (0.021)	0.016 (0.010)
Diff Renewable commodity index	0.008 (0.012)	-0.072** (0.032)	-0.033 (0.030)	-0.019 (0.015)
Diff Productivity Differential	0.023*** (0.007)	0.006 (0.020)	0.009 (0.032)	0.007 (0.016)
Diff Real Interest Rate Differential	-0.000 (0.001)	0.005*** (0.001)	0.004** (0.002)	0.003*** (0.001)
Constant	0.619*** (0.088)	0.352** (0.167)	0.266* (0.152)	0.594*** (0.090)

Note: The table reports the panel ARDL regression estimates of Equation (2) with robust standard errors in parentheses for the country groups in columns 1-4. The *, ** and *** notations denote 10, 5 and 1 percent significance levels, respectively. Diff denotes the first difference.

Another parameter of interest is the long-run fossil commodity price elasticity of the real exchange rate, which shows a positive and economically significant estimate for advanced economies and commodity exporters. The results indicate, for example, that a 10% increase in real fossil commodity prices is associated with a 0.9% appreciation in the real exchange rate for advanced economies and approximately a 2% appreciation for commodity exporters. On the other hand, the long-run renewable commodity price elasticity estimates of the real exchange rate exhibit a positive sign but are not economically important in explaining the long-run exchange rate movement for all groups in columns 1-4. Similarly, the Balassa-Samuelson effect, measured by the productivity differential, is positively associated with long-run real exchange rate movements as expected, but it is statistically insignificant factor to explain real exchange rate movements only for commodity importers. Furthermore, our results demonstrate that the long-run real interest rate differential elasticity has mixed effects. It is important for explaining the real exchange rate movement in the long run only for advanced countries. Surprisingly, for other groups, the real interest rate differential is not a significant factor in explaining their long-run equilibrium real exchange rate movements.

Overall, Table 9 presents the short-term impacts of changes in fossil commodity prices on the real exchange rates of different economies. The results indicate that these price changes have a positive correlation with the real exchange rate for advanced economies, emerging economies, and commodity exporters. This suggests that fluctuations in fossil commodity prices play a significant role in explaining short-term movements in the real exchange rates of these economies, with the exception of commodity importers. Specifically, the estimates show that a 10% increase in fossil commodity prices is typically associated with a 0.9-0.2% appreciation in the real exchange rate for these economies in the short term. On the other hand, the short-term changes in the renewable commodity price index (specifically, metal-mineral commodity prices) only have a negative association with the real exchange rate changes for emerging economies. Furthermore, the short-term changes in the productivity differential are found to be significant and positively correlated with the real exchange rate, but only for advanced economies. Although a positive relationship is observed for other groups of economies as well, the Balassa-Samuelson effects in the short term do not play a substantial role in explaining their real exchange rate movements.

In addition, our research demonstrates that short-term fluctuations in the real interest rate differential are both positively correlated and economically significant in explaining short-term movements in the real exchange rate for emerging economies, as well as for both commodity importers and exporters. In summary, the findings suggest that changes in fossil commodity prices have economically important implications for explaining short-term real exchange rate developments in various economies, except for commodity importers. Additionally, the impacts of renewable commodity price changes and productivity differentials vary across different groups of economies, indicating the complexity of these relationships. It is important to note that our results are innovative, as previous studies have primarily focused on a country-by-country analysis (Ricci et al., 2013; Habib and Kalamova, 2007; Cashin et al., 2004; Chen and Rogoff, 2003). However, we have extended our analysis to examine the relationship between the real exchange rate and its fundamental factors on a country-by-country basis in the following section.

4.4.4 Identification of fossil and renewables currencies

This section focuses on identifying the real exchange rates of countries that have a strong long-term relationship with their economic fundamentals, particularly in relation to the prices of fossil and renewable energy in the market. More specifically, when we find a real exchange rate of a country that has a significant long-term equilibrium relationship with either the price index of fossil energy or renewable energy, we categorize the currency of that country as either a *fossil* or a *renewable* currency. To conduct our analysis, we followed previous literature and employed a country-by-country unit root analysis and cointegration tests (Habib and Kalamova, 2007; Cashin et al., 2004; Chen and Rogoff, 2003). Tables 2a and 2b above show the results of the unit root analysis. Afterwards, we conducted country-by-country cointegration tests to establish the specific type of cointegration and examine the long-term and short-term impacts of the real exchange rate and its fundamentals on these countries. This approach is commonly used in previous research on commodity-currency relationships (Ricci et al., 2013; Habib and Kalamova, 2007; Cashin et al., 2004; Chen and Rogoff, 2003).

Table 10. Cointegration test results for the real exchange rate and its main determinants at the country level.

Johansen trace test				
Countries in favour of cointegration; at least one or more fundamentals				
Countries	r=0	r≤1	r≤2	r≤3
Australia	76.91**	47.31**	23.56	9.47
Belgium	91.58**	47.38**	20.97	8.90
Brazil	73.50**	43.31	21.71	5.82
Finland	88.65**	45.64	25.99	10.17
Malaysia	80.34**	39.38	21.27	7.31
New Zealand	72.99**	44.61	17.95	2.56
Norway	72.79**	37.35	19.11	5.81
Mexico	76.13**	41.49	19.74	3.53
Philippines	74.62**	43.35	21.02	5.41
Saudi Arabia	74.05**	47.08	24.57	6.16
South Africa	92.49**	38.02	18.06	2.85

Note: This table reports the Johansen cointegration (trace-test) estimates based on the countries whose real exchange rates are found to cointegrate with fundamentals consisting of fossil price index, renewable price index, productivity, and real interest rate differentials. The estimates reported are based on Johansen (2000, 2002) cointegration test with critical values for the trace-test as r=0: 68.52, r≤1: 47.21, and r≤2: 29.68 respectively, where r refers to the number of cointegration vectors. The test results are reported at 5% significance level.

Additionally, to examine and identify potential cointegrating relationships, we utilized the Johansen (2000, 2002) trace-test, which is a likelihood ratio test calculated using the Bartlett correction factor. The estimated results are presented in Table 10. This table provides the findings for specific countries where we discovered cointegration between their real exchange rates and fundamental variables. In this portion of the analysis, we found evidence of cointegration vectors for 11 countries. For these countries, we rejected the null hypothesis of no cointegration (r=0) at a 5% level of significance. This suggests that the real exchange rates of these countries share a common long-term equilibrium relationship with one or more fundamental factors, such as the fossil price index, renewable price index, productivity, and real interest rate differentials.

On the other hand, for the remaining 15 countries, we did not find any evidence of cointegrating vectors. Specifically, the null hypothesis of no cointegration between the real exchange rate and its fundamentals could not be rejected for these countries. This implies that the real exchange rates of these countries do not share a common long-term equilibrium relationship with their fundamental variables[41]. Moving forward, we proceed to examine the long- and short-run impacts of the fundamental variables on the real exchange rate for the countries listed in Table 10. To do so, we employ the Engle and Granger (1987) two-step Error Correction Model (ECM) procedure. This particular approach allows us to identify the potential fundamental factors that are significant in explaining the long-term movements of the equilibrium exchange rate, as well as the short-term effects for these countries.

4.4.4.1 Long run elasticities and short-run impacts

Tables 11 and 12 presented below illustrate the long-run elasticity estimates and the corresponding short-run impacts for the countries in which the real exchange rates were found to be cointegrated with their fundamentals. The estimates reported in these tables demonstrate that the error correction (ECT) parameters exhibit a negative sign and are economically significant for all 11 countries, which aligns with expectations. This indicates that the real exchange rates of these countries share a common long-run trend with their fundamentals. These findings support the long run cointegration relation identified among the variables in Table 10. The statistical significance of the negative sign implies that, following a shock, the real exchange rate adjusts back to its long-run equilibrium value. The estimated ECT values for the real exchange rates in Tables 11 and 12 suggest that approximately 11% to 55% of the deviation from the long-run equilibrium is corrected within one year. Consequently, the half-life of the real exchange rate deviation from its long-run equilibrium value ranges between 1 to 3 years for these countries.

When focusing on the parameter of interest, the long-run elasticity estimates reported in Tables 11 and 12 clearly demonstrate the significant potential to explain the movements of the long-run equilibrium exchange rates

[41] The cointegration results of the 15 countries are available upon request

for the countries under study. Specifically, the results reveal a common long-run equilibrium trend between the real exchange rates of eight countries and either the fossil commodity price index, the renewable commodity price index, or both. Notably, Australia, Norway, Mexico, and Saudi Arabia exhibit an economic association with both the commodity price indices, indicating their status as major commodity exporters. Previous studies have often referred to countries with a strong long-run relationship between their real exchange rates and real commodity prices as *commodity currencies* (e.g., Kohlseen et al., 2016; Chen and Rogoff, 2003; Cashin et al., 2004; Habib and Kalamova, 2007). In this paper, we classify currencies as either *fossil* or *renewable* currencies if the real exchange rate of a country shares a economically significant long-run equilibrium relationship with either the fossil or renewable commodity price index.

Additionally, the estimates presented in Tables 11 and 12 demonstrate a long-term relationship between the real exchange rates of Malaysia, New Zealand, Belgium, and South Africa, and the renewable commodity price index. The significant long-run elasticity estimates indicate that these currencies can be considered as *renewable currencies*. Likewise, the results show that the real exchange rates of Norway and Saudi Arabia are positively and economically significantly associated with the fossil commodity price index in the long run. As these countries are known for being major fossil energy producers, it is economically reasonable to consider their currencies as *fossil currencies*. These findings align with previous research by Habib and Kalamova (2007).

Table 11. Empirical results of long run elasticities and short-run impact of real exchange rate for the countries

Dependent variable: Real exchange rate						
	Australia	Norway	Mexico	Saudi Arabia	Malaysia	New Zealand
Error correction term (ECT)	-0.51*** (0.133)	-0.308** (0.126)	-0.553*** (0.194)	-0.112** (0.055)	-0.209*** (0.070)	-0.452*** (0.141)
Long run relations						
Fossil commodity price index	0.161*** (0.034)	0.0521** (0.021)	0.107* (0.058)	0.457*** (0.088)	-0.0408 (0.068)	-0.028 (0.037)
Renewable commodity price index	0.174** (0.071)	0.0175 (0.040)	-0.360*** (0.095)	-0.199 (0.154)	-0.301** (0.126)	0.304*** (0.061)
Productivity Differential	0.96*** (0.339)	0.329*** (0.060)	0.0472 (0.049)	0.573*** (0.112)	0.132** (0.059)	0.084 (0.116)
Real Interest Rate Differential	-0.003 (0.004)	-0.007** (0.002)	0.004*** (0.000)	0.025 (0.018)	0.031*** (0.007)	-0.0017 (0.003)
Short run effects						
Diff Fossil commodity index	-0.169*** (0.042)	-0.043 (0.026)	0.0607 (0.092)	0.026 (0.039)	-0.0656 (0.052)	-0.104** (0.042)
Diff Renewable commodity index	-0.014 (0.057)	0.013 (0.032)	0.097 (0.109)	0.055 (0.048)	0.0214 (0.053)	-0.058 (0.058)
Diff Productivity Differential	0.452 (0.478)	-0.141 (0.078)	0.085 (0.076)	-0.055 (0.066)	0.0079 (0.037)	0.010 (0.120)
Diff Real Interest Rate Differential	0.004 (0.004)	0.0013 0.002	0.003 (0.002)	0.002 (0.004)	-0.003 (0.004)	0.001 (0.002)
Constant	2.944*** (0.278)	4.133*** (0.140)	5.678*** (0.313)	6.11*** (0.470)	5.604*** (0.425)	3.344*** (0.181)

Note: This table reports the estimates of the Engle and Granger (1987) two-step Error Correction Model (ECM) estimation with robust standard errors in parenthesis for the countries whose real exchange rate is found to be cointegrated with its fundamentals. The *, ** and *** notations denote 10, 5 and 1 percent significance levels, respectively.

Table 12. Empirical results of long run elasticities and short-run impact of real exchange rate for the countries

Dependent variable: Real exchange rate					
	Belgium	Brazil	Philippines	Finland	South Africa
Error correction term (ECT)	-0.55*** (0.123)	-0.301** (0.120)	-0.266** (0.112)	-0.234* (0.133)	-0.242*** (0.073)
Long run relations					
Fossil commodity price index	-0.016 (0.019)	-0.092 (0.088)	0.069 (0.057)	-0.139 (0.132)	-0.090 (0.105)
Renewable commodity price index	0.075** (0.034)	0.149 (0.158)	-0.153 (0.100)	0.091 (0.055)	0.392** (0.177)
Productivity Differential	-0.235 (0.210)	0.204** (0.076)	0.054** (0.026)	0.860*** (0.172)	0.007 (0.098)
Real Interest Rate Differential	0.000 (0.001)	0.013 (0.009)	0.003 (0.006)	-0.009** (0.003)	0.0193** (0.009)
Short run effects					
Diff Fossil commodity index	-0.021 (0.018)	-0.082 (0.092)	-0.046 (0.056)	0.005 (0.035)	-0.051 (0.064)
Diff Renewable commodity index	-0.011 (0.024)	0.092 (0.124)	0.037 (0.068)	0.036 (0.042)	-0.063 (0.085)
Diff Productivity Differential	-0.448 (0.340)	0.113 (0.074)	-0.007 (0.027)	0.471 (0.278	0.099 (0.059)
Diff Real Interest Rate Differential	0.000 (0.000)	0.012 (0.011)	-0.009** (0.003)	0.0046 (0.003)	-0.009* (0.005)
Constant	4.342*** (0.152)	3.85** (0.493)	5.13*** (0.358)	4.769*** (0.164)	6.78*** (0.580)

Note: This table reports the estimates of the Engle and Granger (1987) two-step Error Correction Model (ECM) estimation with robust standard errors in parenthesis for the countries whose real exchange rate is found to be cointegrated with its fundamentals. The *, ** and *** notations denote 10, 5 and 1 percent significance levels, respectively. Diff denotes differenced values.

In examining the unique cases of Australia and Mexico, our research indicates that the real exchange rate in these countries is economically linked to both fossil and renewable commodity price indices. Furthermore, the estimates of the long-run elasticity of their real exchange rate relations are statistically significant. These findings align with previous studies that have considered these countries as *commodity currencies*, utilizing aggregate commodity price indices[42] (Cashin et al., 2004; Chen and Rogoff, 2003). Overall, our findings highlight the importance of long-run estimations of energy market-related commodity prices, including fossil and renewable commodities, in explaining equilibrium exchange rate movements in these countries.

Furthermore, in our estimation, we controlled for the Balassa-Samuelson effect by using the productivity differential as a proxy. The long-term elasticity estimates for this aspect indicate that the productivity differential plays a crucial role in explaining the movements of the long-run equilibrium exchange rates for certain countries. More specifically, we found that the long-run elasticity of the productivity differential in relation to the real exchange rate is positive and economically significant for Australia, Norway, Malaysia, Saudi Arabia, Brazil, Philippines, and Finland. This result implies that the productivity differential is a significant determinant in explaining the long-term movements of the real exchange rate, which aligns with our initial expectations. In economic terms, our estimates suggest that an increase in the productivity differential tends to lead to an appreciation of the real exchange rate in these countries. Additionally, we analyzed another traditional fundamental determinant of the long-run deviation of the exchange rate from Purchasing Power Parity (PPP), namely the real interest rate differential. Our analysis revealed that the real interest rate differential plays an important role in explaining the movements of the long-run equilibrium real exchange rate for five countries, namely Norway, Mexico, Malaysia, Finland, and South Africa. The estimates presented in Tables 11 and 12 provide evidence for the significance of the real interest rate differential as a fundamental factor in understanding the dynamics of the long-run equilibrium real exchange rate movement.

In summary, the estimates presented in Tables 11 and 12 suggest that the short-term effects of the fundamentals are not economically significant in explaining the changes in the real exchange rates for most of the countries analyzed. However, for Australia and New Zealand, we find that the changes in the fossil commodity price index have a negative and statistically significant association with the changes in the real exchange rate in the short run. Furthermore, since we have identified several significant long-run relationships in our estimation, we have also conducted robustness tests using an alternative approach commonly employed in previous research.

4.4.4.2 Robustness tests controlling for the endogeneity

To evaluate the consistency of long-run estimates using the Engle and Granger (1987) two-step error correction method, we conducted additional analyses as robustness checks. Previous research on commodity currencies typically employed the Dynamic OLS (DOLS) approach, as demonstrated by Chen and Rogoff (2003), or the Fully Modified least squares (FM-OLS) model, also utilized by Habib and Kalamova (2007) and Cashin et al. (2004). In most cases, the FM-

[42] Aggregate commodity price index includes agricultural products', metals and minerals, and energy

OLS estimation method is preferred. This approach employs a semiparametric regression that adjusts the least squares regression model to address potential endogeneity of the regressors and serial correlation arising from cointegrating relationships. Cashin et al. (2004) demonstrated that the FM-OLS method generates an asymptotically correct variance-covariance estimator when estimating cointegrating vectors in the presence of serial correlation and endogeneity. The model for our analysis is represented as

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon_t, \quad t = 1 \ldots . T, \; \varepsilon_t \sim iid(o, \sigma^2), \qquad 5$$

where y_t is the real exchange rate at time t, and x_t is the vector of fundamentals (i.e., fossil commodity price index, renewable commodity price index, productivity, and real interest rate differentials) at time t. For all the FMOLS cointegrating estimations we employ the Bartlett kernel, Andrews' (1991) automatic bandwidth selector and the pre-whitened kernel estimator of Andrews and Monahan (1992).

Tables 13 and 14 provide the long-run (cointegration) regression results for the real exchange rate and its fundamentals-based approach using the FMOLS method. Overall, the estimated long-run relationships between the real exchange rates and the underlying fundamentals confirm the robustness and consistency of the previous findings. While there may be slight differences in the coefficients' magnitudes, their signs and economic significance remain consistent with the earlier results. Consequently, these findings support previous studies that have also observed a long-term co-movement between the real exchange rate of other countries and their respective fundamental factors, as documented in the aforementioned tables (Ricci et al., 2013; Peltonen and Sager, 2009; Jaunky, 2008; Chen and Rogoff, 2003).

Table 13. Empirical results of real exchange rate and its fundamental determinants using the FMOLS approach

Dependent variable: Real exchange rate						
	Australia	Norway	Mexico	Saudi Arabia	Malaysia	New Zealand
Long run relations						
Fossil commodity price index	0.216*** (0.054)	0.050 (0.035)	0.183*** (0.057)	0.330*** (0.099)	-0.005 (0.105)	-0.019 (0.050)
Renewable commodity price index	0.187 (0.118)	0.021 (0.065)	-0.494*** (0.093)	-0.502*** (0.173)	-0.284*** (0.094)	0.328*** (0.082)
Productivity Differential	1.274** (0.590)	0.357*** (0.098)	0.036 (0.048)	0.787*** (0.180)	0.162** (0.070)	0.092 (0.155)
Real Interest Rate Differential	-0.003 (0.007)	-0.011*** (0.004)	0.001** (0.000)	0.038 (0.028)	0.037*** (0.012)	0.004 (0.004)
Constant	2.63*** (0.461)	4.07*** (0.237)	5.91*** (0.307)	5.81*** (0.526)	5.87*** (0.653)	3.23*** (0.242)

Note: This table reports the estimates of FMOLS estimation based on Equation 5 with robust standard errors in parenthesis for the countries in Table 10. The *, ** and *** notations denote 10, 5 and 1 percent significance levels, respectively.

Table 14. Empirical results of real exchange rate and its fundamental determinants using the FMOLS approach

Dependent variable: Real exchange rate					
	Belgium	Brazil	Philippines	Finland	South Africa
Long run relations					
Fossil commodity price index	-0.018 (0.026)	-0.188 (0.133)	0.070 (0.085)	-0.1579 (0.138)	-0.052 (0.155)
Renewable commodity price index	0.119*** (0.045)	0.080 (0.115)	-0.208 (0.148)	0.064 (0.065)	-0.623** (0.257)
Productivity Differential	-0.432 (0.277)	0.476** (0.239)	0.099** (0.039)	0.519*** (0.197)	-0.137 (0.142)
Real Interest Rate Differential	-0.001 (0.002)	0.009 (0.014)	0.005 (0.009)	-0.011 (0.004)	0.013 0.017
Constant	4.147*** (0.200)	3.10*** (0.746)	5.50** (0.532)	4.96*** (0.193)	7.72*** (0.860)

Note: This table reports the estimates of FMOLS estimation based on Equation 5 with robust standard errors in parenthesis for the countries in Table 10. The *, ** and *** notations denote 10, 5 and 1 percent significance levels, respectively.

4.5 Concluding remarks and recommendations

The issue of greenhouse gases and inflation has become increasingly urgent at the global decision-making level. Governments, multinational institutions, and private organizations are grappling with the challenges posed by rising commodity prices, especially in the aftermath of the COVID-19 pandemic and the ongoing Russia-Ukraine conflict. Consequently, it is crucial to investigate the effects of escalating commodity prices and their associated economic impacts, not only at the country level but also on a global scale.

In light of this, our study aims to examine the impact of greenflation, defined as the rising prices in renewable-related commodity markets during the transition to a greener global economy, as well as the real exchange rate exposures among industrialized and emerging nations. Our findings indicate that greenflation is predominantly driven by factors within the global commodity demand chain. These factors encompass the increasing consumption of renewable energy, rising imports of commodities necessary for green energy production, climate change considerations, and global inflation. According to our results, these interconnected factors play significant roles at both regional and global levels.

Furthermore, our study reveals that fluctuations in fossil commodity sub-sector prices contribute to the movements in the long-run equilibrium real exchange rates for countries like Norway and Saudi Arabia. On the other hand, the renewable energy sector demonstrates a notable influence on the real exchange rates of Malaysia, New Zealand, Belgium, and South Africa. In summary, our findings highlight that demand chain factors, climate change, and inflation are the primary drivers of increasing commodity prices.

Based on the findings of our study, we have the following policy recommendations to address the challenges posed by greenflation and its impact on exchange rates: Governments should continue to encourage investments in renewable energy infrastructure, such as solar and wind power, to reduce dependence on fossil fuels and mitigate the demand-side drivers of greenflation. This can be achieved through incentives, tax breaks, and supportive policies for renewable energy projects.

Additionally, it is essential to support sustainable resource management practices in the production of renewable energy commodities. This includes promoting responsible mining and extraction techniques, recycling initiatives, and reducing waste in the production and consumption of renewable energy resources. These measures can help alleviate supply-side pressures on greenflation. And lastly, policymakers should prioritize efforts to mitigate climate change, as it is a major driver of greenflation. Implementing effective policies to reduce greenhouse gas emissions and transition to net zero emission.

APPENDIX 4.A

Table A.1. Empirical results for the analysis of greenflation determinants; Country effect

Dependent variable: Greenflation						
Countries	Constant γ_0	Renewable energy consumption	Metal imports	Inflation (ΔPPI)	R2	N
Australia	-0.04* (0.02)	0.26 (0.75)	0.54*** (0.09)	0.02*** (0.02)	0.57	41
Austria	0.03 (0.03)	0.92 (3.50)	0.21*** (0.04)	0.00 (0.01)	0.43	41
Belgium	-0.01 (0.03)	0. (1.99)	0.03 (0.03)	0.02*** (0.00)	0.22	41
Brazil	0.02 (0.03)	-0.24 (0.49)	0.29*** (0.05)	0.00 (0.00)	0.57	41
Canada	0.05** (0.02)	0.89*** (0.46)	0.42*** (0.07)	0.00 (0.00)	0.60	41
Chile	0.01 (0.03)	0.28 (0.37)	0.14 (0.09)	limited data	0.16	41
China	-0.01 (0.02)	0.14** (0.04)	0.06** (0.02)	limited data	0.46	41
Finland	-0.00 (0.02)	0.07 (1.62)	0.12*** (0.02)	0.01* (0.00)	0.54	41
France	0.08** (0.03)	0.08 (0.58)	0.42*** (0.05)	0.03*** (0.01)	0.61	41
Germany	0.04 (0.03)	0.05 (0.17)	0.24*** (0.04)	0.00 (0.01)	0.59	41
Italy	0.03 (0.02)	0.14 (0.30)	0.23*** (0.03)	-0.00 (0.00)	0.57	41
Japan	0.05** (0.02)	0.09** (0.03)	0.20*** (0.02)	0.00 (0.00)	0.65	41
Malaysia	-0.00 (0.02)	Limited data	0.25*** (0.06)	0.01*** (0.00)	0.42	41
Mexico	0.02 (0.04)	0.06 (2.66)	0.03 (0.09)	0.00 (0.00)	0.5	41
Nether-lands	0.00 (0.02)	0.67 (0.57)	0.27*** (0.05)	0.01*** (0.00)	0.54	41
Norway	-0.01 (0.02)	0.13** (0.05)	0.12*** (0.02)	0.01*** (0.00)	0.57	41
New Zealand	0.01 (0.04)	0.30 (0.32)	0.16*** (0.04)	0.01 (0.01)	0.32	41
Philippines	0.06 (0.04)	0.05 (0.19)	0.00 (0.07)	0.00 (0.01)	0.06	41
Singapore	0.03 (0.03)	0.30 (0.81)	0.14 (0.14)	No data	0.05	41
South Africa	0.02 (0.03)	Limited data	0.18** (0.07)	0.00 (0.00)	0.14	41
Spain	0.01 (0.02)	0.36 (0.65)	0.24*** (0.08)	0.01 (0.01)	0.47	41
Saudi Arabia	0.02 (0.02)	Limited data	0.16** (0.06)	No data	0.19	41
Sweden	0.03 (0.05)	0.25 (1.54)	0.28*** (0.06)	0.01* (0.00)	0.49	41
Switzer-land	0.02 (0.04)	0.29 (1.20)	0.06** (0.02)	0.01 (0.00)	0.17	41
UK	0.04 (0.03)	0.51 (0.31)	0.24*** (0.04	0.01**(0.00)	0.30	41
USA	0.02 (0.03)	0.05 (0.11)	0.40*** (0.08)		0.41	41

Note: This table reports the parameter estimates for the Equation (3) with robust standard errors in parenthesis. *, **, and *** denote 10, 5, and 1% significance levels, respectively. Δ denotes the change in the variable in question.

Table A.2. Details of date sources and description

Variables	Description and source	Period
Real exchange rate	Real effective exchange rate based on consumer price index. IMF-IFS. Calculated as a geometric weighted average of bilateral real exchange rates between home country and its trade partners	1980-2021
Fossil price index	Energy commodity price index (nominal); coal, crude and natural gas. Pink sheet-World Bank	1980-2021
Renewable price index	Metal and minerals commodity price index (nominal); aluminium, copper, nickel, iron ore, tin and zinc. Pink sheet-World Bank	1980-2021
Renewable energy consumption	Renewable power based on gross generation, not accounting for cross-border electricity supply. From bp.com/statisticalreview.	1980-2021
Solar energy consumption	Solar power based on gross generation, not accounting for cross-border electricity supply. From bp.com/statisticalreview.	1980-2021
Wind energy consumption	Wind power based on gross generation, not accounting for cross-border electricity supply. From bp.com/statisticalreview.	1980-2021
Global inflation (PPI)	Prices, Producer Price Index, All Commodities, Index. IMF-IFS	1980-2021
Metal import	Ores and metals imports (% of merchandise imports). (Ores and metals comprise commodities in SITC sections 27 (crude fertilizer, minerals); 28 (metalliferous ores, scrap); and 68 (non-ferrous metals). WDI-World Bank	1980-2021
Metal exports	Ores and metals exports (% of merchandise exports). (Ores and metals comprise commodities in SITC sections 27 (crude fertilizer, minerals); 28 (metalliferous ores, scrap); and 68 (non-ferrous metals). WDI-World Bank	1980-2021
Climate change	Annual estimates of mean surface temperature change with respect to a baseline climatology. IMF	1980-2021
Tradeable sector	Value added per worker is a measure of labor productivity—value added per unit of input. Value added denotes the net output of a sector after adding up all outputs and subtracting intermediate inputs. Agriculture and industry are the tradable sector includes forestry, hunting, and fishing, mining and quarrying manufacturing, and construction. WDI-World Bank	1980-2021
Non-tradeable sector	Value added per worker is a measure of labor productivity—value added per unit of input. Services are non-tradeable includes wholesale and retail trade and restaurants and hotels; transport, storage, and communications; financing, insurance, real estate, and business services; and community, social and personal services. WDI-World Bank	1980-2021
Real interest rate	Real interest rate is the lending interest rate adjusted for inflation as measured by the GDP deflator. WDI-World Bank	1980-2021

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5 SHOCK AND SPILLOVER EFFECTS OF GLOBAL COMMODITY MARKETS ON SOME AFRICAN EQUITY MARKETS

Abstract.
This study aims to investigate the dynamic shock and spillover effects of international commodity markets on selected African equity markets using two analytical approaches – VAR-GARCH and DCC-GARCH. Our findings affirm the efficient-market hypothesis (EMH), indicating no predictability of equity returns in the African equity markets based on the first-moment equation. However, the second-moment equations reveal statistically significant risk and shock spillovers from international commodity markets to African equity markets, along with spillover effects from global implied volatility indicators. Furthermore, our analysis discloses that the risk effects are not constant over time, exhibiting an inclination to become stronger during periods of heightened market risks, particularly during and after the global financial crisis (GFC). In summary, the results highlight the significant role of the financialisation of commodity markets in propagating commodity market risks to African equity markets.

Keywords: commodity prices, volatility spillover, Africa, equity market returns, dynamic conditional correlation
JEL Codes: C32 G12 G15 Q4

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5.1 Introduction

Decades have passed since the 2008–2009 global recession, and the world's financial architecture has since evolved into a complex network of interconnected financial and commodity markets. This integration has primarily occurred due to cross-border investments and trade. Consequently, the transmission of shocks between markets has become more pronounced, particularly in relation to equity and commodity markets following the global financial crisis (GFC). One contributing factor to this increased interdependence is the financialisation of commodity markets, a phenomenon where institutional investors and fund managers consider commodities as an additional asset class, seeking arbitrage opportunities and risk diversification. This trend has added complexity to global financial markets and altered portfolio allocation strategies across various markets. Consequently, researchers are diligently analysing data to gain insights into the dynamic risk and shock transmission between markets, specifically between equity and commodities in different regions. This study aims to shed light on the interplay between these markets and assist investors in making informed decisions regarding risk management and diversification strategies in the African context.

Earlier studies conducted in various countries and regions have extensively explored the relationship between commodity markets such as crude oil, gold, silver, platinum, cocoa, and equity markets. For instance, research conducted in South Asia (Noor and Dutta, 2017), Lebanon and Jordan (Bouri, 2015a, 2015b), Europe (Arouri et al., 2012), China (Arouri et al., 2015), Gulf Cooperation Council [GCC] countries (Arouri et al., 2011; Mensi et al., 2016), the United Kingdom [UK] and the United States [US] (Chang et al., 2013; Junttila et al., 2018; Junttila and Raatikainen, 2017; Mensi et al., 2013), Ghana and Nigeria (Lin et al., 2014), Africa (Boako and Alagidede, 2016), and Brazil, Russia, India, China, and South Africa [BRICS] (Pandey and Vipul, 2017; Mensi et al., 2014) have examined the risk (volatility) or shock transmission between these markets.

This paper makes several contributions to the existing literature. Firstly, it addresses a significant gap by focusing on the African region. Despite its crucial role in the global context as a contributor to the world commodity export markets and a viable investment destination in recent years, previous studies have paid little attention to this region, which is surprising. Secondly, most of the previous research primarily focused on specific commodities such as oil, gold, or individual commodity market indices. While these commodities are considered essential due to their global demand and their role as speculative or hedging assets, relying solely on them may not provide comprehensive measures. This paper distinguishes itself from the existing literature by using more aggregate price measures, encompassing agricultural products, minerals, and energy. Moreover, the paper also considers the role of global investors and consumer anticipation of future commodity price movements. This is measured through implied volatility indices, similar to the VIX index. It is worth noting that this aspect has not yet been explored in previous research focusing on commodities in the African context, making this study unique and innovative.

The region under investigation holds significant importance due to the recent economic growth observed in several African countries. This growth can be attributed, in part, to the expansion of equity and commodity markets. From 2013 to 2017, commodity exports alone contributed an average of 5.1% to 42.2% of the GDP in African countries (UNCTAD, 2019). Moreover, these countries rely heavily on commodity exports, which make up at least 60% of their total merchandise exports (Table B.1). These exports encompass various sectors such as agriculture, energy, fuel, precious metals, stones, and non-monetary gold, making them vital components of these economies' real sectors and export activities. Considering the growth trajectory, it is worth noting that equity market capitalization as a percentage of GDP has increased by approximately 10% between 2011 and 2019. Additionally, foreign companies are increasingly listing on African equity markets, while foreign investor participation has also experienced considerable growth during the post-global financial crisis period (see Table B.2). These developments underscore the expanding presence of the African market and emphasise the need to include it in research related to risk and shock spillovers.

As the African market continues to demonstrate its economic significance through growth miracles, fuelled by expansions in both equity and commodity markets, it becomes increasingly crucial not to overlook it in the body of research focused on understanding risk and studying shock spillovers. Therefore, this study aims to investigate the spillover effects of shocks and risks between global commodity markets and African equity markets. To achieve this, we utilise commodity price indices for agricultural products, energy, and precious metals, along with implied volatility indices. Our choice of using an aggregate price measure is based on the idea that it encompasses various commodities that have not been extensively studied in relation to equity market shocks or risks. In essence, we believe it is crucial to consider the impact of every commodity on the global market. Furthermore, our analysis reveals a substantial unconditional price correlation between more general sectoral indices, such as agricultural products, energy, and precious metals, and specific commodities like crude oil, gold, and corn (refer to Table 2). This emphasis on broader index levels allows us to highlight the correlations among these three extensively analysed commodities.

Moreover, our study employs global market indices on implied volatility, specifically for crude oil, gold, and corn, sourced from the Chicago Board Options Exchange (CBOE). These indices offer insights into global consumer expectations regarding future price movements in the underlying commodity market for a 30-day period. The consideration of these indices will also assist foreign investors in assessing the sensitivity of African equity markets to anticipated uncertainty in the commodity markets, aiding in portfolio allocation decisions. To achieve our research objectives, we employed a multivariate vector autoregressive generalized autoregressive conditional heteroscedasticity (VAR-GARCH) model, introduced by Ling and McAleer (2003). Additionally, we utilised the dynamic conditional correlation (DCC-GARCH) model developed by Engle (2002). This analytical approach enables us to simultaneously investigate shock transfers, volatility spillovers, and the dynamics of conditional interdependence between the markets. The paper utilised daily data spanning from April 1, 2011, to September 30, 2019.

The empirical results obtained from the analysis of the first-moment equation fail to provide evidence supporting equity return predictability in the African market. These results strongly align with the efficient-market hypothesis (EMH), suggesting that investors cannot rely on past information from commodity markets to generate abnormal profits in the African equity market. However, alternatively, the analysis of the second moment equation reveals statistically significant risk and shock spillover effects from the international commodity markets and implied volatility indexes to the African equity markets. This finding implies that the African equity market is closely interconnected with the global financial markets and cannot be analysed in isolation. These interdependencies are dynamic and vary over time, particularly increasing when market risks are higher. These results have important implications for speculative arbitrageurs, market hedgers, and international investors. For instance, they highlight the significance of considering periods of negative time-varying correlations for effective hedging between market risks. It is worth noting that such hedging possibilities may be more limited in the current context of heightened global market interconnections. In summary, our findings reveal that the risk level in the African equity market is influenced by risks originating from global commodity markets and the anticipation of commodity market risks by global investors, as reflected in the implied volatility indices. This finding also suggests that the increasing financialisation of commodity markets has had an impact on African equity markets in recent years.

The paper is organized as follows: Section 5.2 provides an overview of the econometric models and data utilized in this study. Section 5.3 presents the empirical results and corresponding discussions. Lastly, Section 5.4 concludes the paper and offers suggestions for future research.

5.2 Methodology and data

5.2.1 Econometric framework

This paper employs a time-varying conditional correlation multivariate framework to model conditional volatility and shock effects. Specifically, we utilise two widely used models in the literature: VAR-GARCH and DCC-GARCH. The VAR-GARCH method, first introduced by Ling and McAleer (2003) and subsequently applied in various studies (e.g. Arouri et al., 2011, Arouri et al., 2012; Mensi et al., 2013; Dutta et al., 2017; Hammoudeh et al., 2009; Chan et al., 2005), serves as the initial stage in our modelling process. This model enables us to investigate volatility spillovers and time-varying conditional interdependence in a multivariate framework. Unlike other possible models, such as BEKK (Baba et al., 1990; Engle and Kroner, 1995) or CCC (Constant Conditional Correlation) models, the VAR-GARCH approach offers the advantage of examining cross-market transferral of shocks and volatility spillover.

The second part of our analysis involves the utilisation of Engle's dynamic conditional correlation generalised autoregressive conditional heteroscedasticity (DCC-GARCH) model (2002). This model enables us to explore time-varying conditional correlations and has been employed in previous studies by Junttila et al. (2018), Mensi et al. (2017), and Arouri et al. (2015). It builds upon the foundation established by Bollerslev's multivariate CCC-GARCH model (1990). By employing the VAR-GARCH and DCC-GARCH models in our research, we can effectively investigate volatility spillovers, time-varying conditional interdependence, and time-varying conditional correlations, thereby building upon the existing literature in this field.

5.2.1.1 VAR-GARCH model

Given the VAR(p)-GARCH (p, q) model's flexibility in capturing the volatility and shock transmissions from one market to the other, we apply the multivariate VAR (1)[43]-GARCH (1,1) model to the log return data. The model specification takes the following form:

$$\begin{cases} r_t = \mu + \zeta r_{t-1} + \varepsilon_t \\ \\ \varepsilon_t = H_t^{1/2} z_t\,, \quad z_t \sim IID(0,1), \end{cases} \tag{1}$$

where $r_{it} = (r_{agr,t}, r_{ene,t}, r_{met,t}, r_{equ,t})'$ is a *4 x 1* vector of log commodity and log equity returns. *agr*, *ene*, *met*, and *equ* denote agricultural, energy, metal commodities, and equity returns, respectively. In the VAR framework, all returns depend on their own lags (r_{t-1}) and the lags of the other returns in the system; μ is a vector of constant terms; ζ is a *4 x 4* matrix of coefficients for the lagged terms; and ε_t is a *4 x 1* vector of errors in the mean equations. In the second setting, the vector of variables consists of $r_t = (I_{OVX,t}, I_{GVX,t}, I_{CVX,t}, r_{equ,t})'$ —that is, a *4 x 1* vector of log-implied volatility indices for the crude oil (OVX), gold (GVX), and corn (CVX) markets and the log of aggregate equity market return for the country i. z_t is a sequence of independently and identically distributed (i.i.d.) random errors and $H_t^{1/2} = diag(\sqrt{h}_{jt})$ is a diagonal matrix for the conditional standard deviation for each element j. The vector of the conditional variance h_{jt} of equity returns and commodity returns or the implied volatility indices is modeled as

$$h_{jt} = c_j + \sum \alpha_{ij}^2\, \varepsilon_{j,t-1}^2 + \sum \beta_{ij}^2\, h_{j,t-1,} \tag{2}$$

or in the matrix form the model can be succinctly written as

$$h_t = c_j + A\varepsilon_{t-1}^2 + Bh_{t-1,}$$

[43] Schwarz and Hannan-Quinn information criteria choose an optimum lag of one to be included in the VAR-GARCH model.

where h_{jt} is a $4 \ x \ 1$ vector of conditional variances of variable j at time t, and for j we have returns on agr = agriculture, *ene* = energy, *met* = precious metals, and equ = equity market for country for each country. Similarly, the same specification is used for the implied volatility indices (OVX, GVX, CVX) and equity returns. Furthermore, c_j is a $4 \ x \ 1$ vector of constants, $A \ and \ B$ are $4 \ x \ 4$ matrix of parameters that includes the $\alpha's$ and $\beta's$ on the squared past errors ε_{jt-1}^2 and past conditional variances of variable j. From this specification, it is clear that the conditional variance h_{jt} depends on its past squared innovations, past conditional variance, and the past squared innovations and conditional variances of the other variables in the system. The setup in Eq. 2 indicates how volatility and shocks are transmitted across commodity and equity markets over time. More precisely, the past innovations ε_{jt-1} capture the direct effects of shock transmission across the markets, representing the short-run persistence effects or the ARCH effects, while h_{jt-1} not only accounts for the GARCH effects in variable j, but it also directly captures the volatility spillovers or risk transfers between the markets. This convenient specification also allows us to analyze the cross-market interdependences of the conditional volatilities. These are captured by the conditional covariance matrix given as

$$h_{j,t} = \rho\sqrt{h}_{l,t}\sqrt{h}_{j,t} \quad l \neq j, \qquad 3$$

where $h_{lj,t}$ is the conditional covariance between variables i and j at time t, $\sqrt{h}_{l,t}$ and $\sqrt{h}_{j,t}$ are the standard deviation estimates of variables l and j at time t, respectively, and ρ is the constant conditional correlation (CCC), which captures the cross-market interdependences in the system. However, owing to the obvious possibilities of structural changes in the markets under analysis, the CCC assumption may not be suitable to analyze the market interdependences: it may be too restrictive or unrealistic an assumption because the conditional correlation parameters may vary over time as the market and economy undergo fundamental changes (see Arouri et al., 2015; Sadorsky, 2014; 1999; Mensi et al., 2013 for previous evidence from some other markets). For this reason, we adopted Engle's DCC-GARCH model (2002) in the second stage.

5.2.1.2 DCC-GARCH model

The application of Engle's multivariate dynamic conditional correlation GARCH (p, q) model (2002) assumes that the *4 x 1* vector of conditional log-returns (r_t) of commodity and equity markets is normally distributed with zero mean and time-varying variance-covariance matrix H_t, and so the conditional observations of returns are given as $r_t|\mathrm{I}_{t-1} \sim N(0, H_t)$, where I_{t-1} denotes the information set at time *t*-1. The model follows a two-stage process. In the first stage, a univariate GARCH (p, q) is estimated for each variable in the vector r_{it}. The standardized residuals are then used to estimate the time-varying conditional variance-covariance matrix from which the time-varying conditional correlations can then be calculated. The multivariate DCC-GARCH model specification with time-varying conditional covariance matrix H_t can then be decomposed as

$$H_t = D_t R_t D_t, \qquad 4$$

where R_t is a matrix containing the time-varying conditional correlations and D_t is a matrix containing the time-varying standard deviations on the main diagonal and zeros off the diagonal, so

$$D_t = diag\ (\sqrt{h}_{iit} \ldots\ldots \sqrt{h}_{nnt}) \quad 5$$

and

$$R_t = diag(Q_t)^{-1} Q_t diag(Q_t)^{-1}. \quad 6$$

Here, $diag(Q_t)^{-1}$is an inverted diagonal matrix defined as

$$diag(Q_t)^{-1} = \begin{bmatrix} 1/\sqrt{q}_{iit} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1/\sqrt{q}_{iit} \end{bmatrix}, \quad 7$$

and the standardized residuals $\varepsilon_{it} = r_{it}/\sqrt{h}_{it}$ are used to estimate the conditional covariance matrix Q_t, given by

$$Q_t = (1 - \theta_1 - \theta_2)\overline{Q} + \theta_1 \varepsilon_{t-1}\varepsilon'_{t-1} + \theta_2 Q_{t-1}. \quad 8$$

Here, Q_t is a symmetric positive definite matrix and $\overline{Q}$ is the $(n\ x\ n)$ unconditional correlation matrix of the standardized residuals, whereas θ_1 , θ_2 are non-negative parameters that must satisfy the stability condition $\theta_1 + \theta_2 < 1$ to ensure that the DCC model is mean reverting. The dynamic or the time-varying conditional correlation (DCC) estimator is given by

$$\rho_{lj,t} = \frac{q_{lj,t}}{\sqrt{q_{ll,t} q_{jj,t}}}\ \ i \neq j, \quad 9$$

where $q_{lj,t}$ is the conditional covariance between variables l and j at time t, $q_{ll,t}$ and $q_{jj,t}$ are the diagonal elements in the conditional covariance matrix Q_t (i.e., the conditional standard deviation estimates of the variables l and j). Because of the normality assumption, (i.e., $r_t|\mathrm{I}_{t-1} \sim N(0, H_t)$), we estimated the model's parameters using maximum likelihood estimation.

5.2.2 Data and descriptive statistics

The daily return series in the paper are derived from three Standard & Poor's 500 (S&P500) commodity market price indices, namely agricultural products, energy, and precious metals. Specifically, we consider the crude oil volatility index (OVX), gold volatility index (GVX), and corn volatility index (CVX), which are obtained from the CBOE. Additionally, we incorporate the MSCI equity market price indices for eight African countries. The data used spans from April 1, 2011, to September 30, 2019, resulting in a comprehensive dataset consisting of 2,217 observations for each variable. All the price series used in this analysis have been extracted from the Thomson Reuters EIKON DataStream.

For our research, we focus on the following African countries: Botswana, Egypt, Kenya, Ghana, Nigeria, South Africa, Uganda, and Zambia. These countries have been chosen based on various factors that make them relevant to our study. By using these data sources and considering these specific countries, we aim to gain insights into the relationship between commodity markets and equity markets in Africa.

The selection of countries for this analysis was based on specific criteria. Firstly, we considered countries that had a sufficient amount of data available. Secondly, we focused on countries with a well-functioning equity market. In addition to these factors, the level of dependence on commodity export markets, as shown in Table B.1, was taken into account when choosing African countries for analysis. Lastly, the level of depth and integration with global financial markets, as outlined in AAFMI (2019), was another criterion considered. It is important to mention that the choice of the sample period was primarily driven by data limitations, particularly for the equity market and implied volatility indices. Daily price series were transformed into log-returns for both equity and commodity indices. This transformation involved taking the first difference of the log prices, represented as $r_{it} = \ln\left(\frac{p_t}{p_{t-1}}\right)$ where p_t and p_{t-1} represent the daily price series at times t and t-1, respectively. To better visualize this information, Figure 1 displays the equity prices and returns series, while Figure 2 presents the commodity market indices.

Table 2 presents the summary statistics for equity returns, commodity indices, and implied volatility indices in panels A–C. The statistics reveal that approximately 60% of the mean equity returns are negative, while all average commodity index returns are also negative (Table 2). Additionally, it is evident that most of the return series exhibit negative skewness. Financial time series often exhibit leptokurtosis, which is also observed in these time series. Furthermore, the returns do not follow a normal distribution, as indicated by the rejection of the null hypothesis of normality at the 1% significance level for all series based on the Jarque-Bera test statistics. In terms of stationarity, the unit root tests conducted using the Augmented Dickey-Fuller and Phillips-Perron tests show that the stock and commodity market price series in levels are non-stationary. Consequently, it is more suitable to use the return series based on log differences of the equity and commodity indices for further analysis.

To provide further support for the use of aggregate commodity indices in this paper, we examined the unconditional correlations between the commodity indices and some individual commodity indices (such as West Texas Intermediate [WTI] crude oil, gold, and corn) that are commonly used in related literature. As shown in Table 1, these correlations are consistently positive and very high. Importantly, the utilization of indices is crucial as they serve as comprehensive information series for the vital commodity markets analyzed in this study (such as oil, gold, and corn).

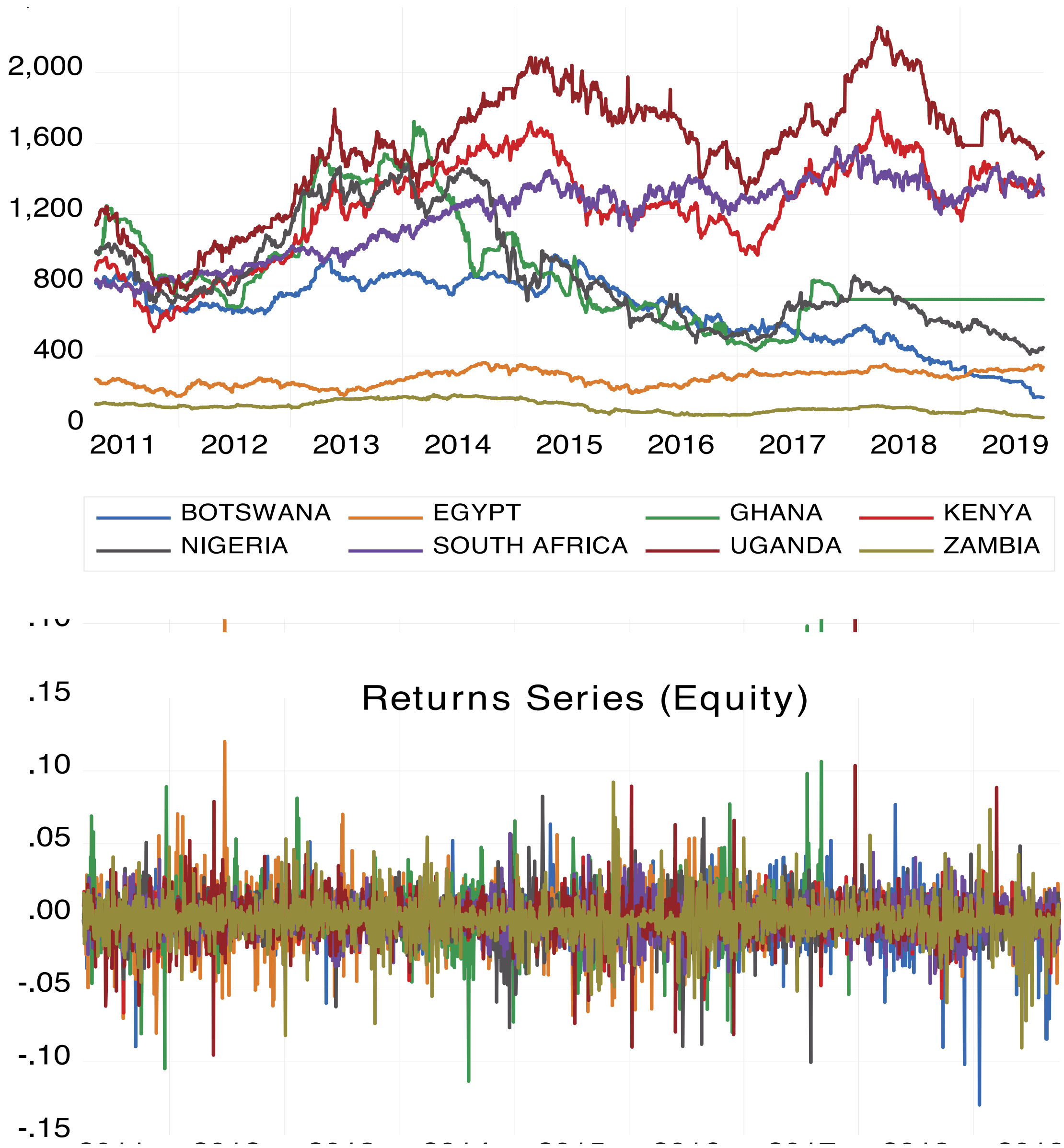

Figure 1. Equity prices (upper panel) and returns (lower panel) series for African countries

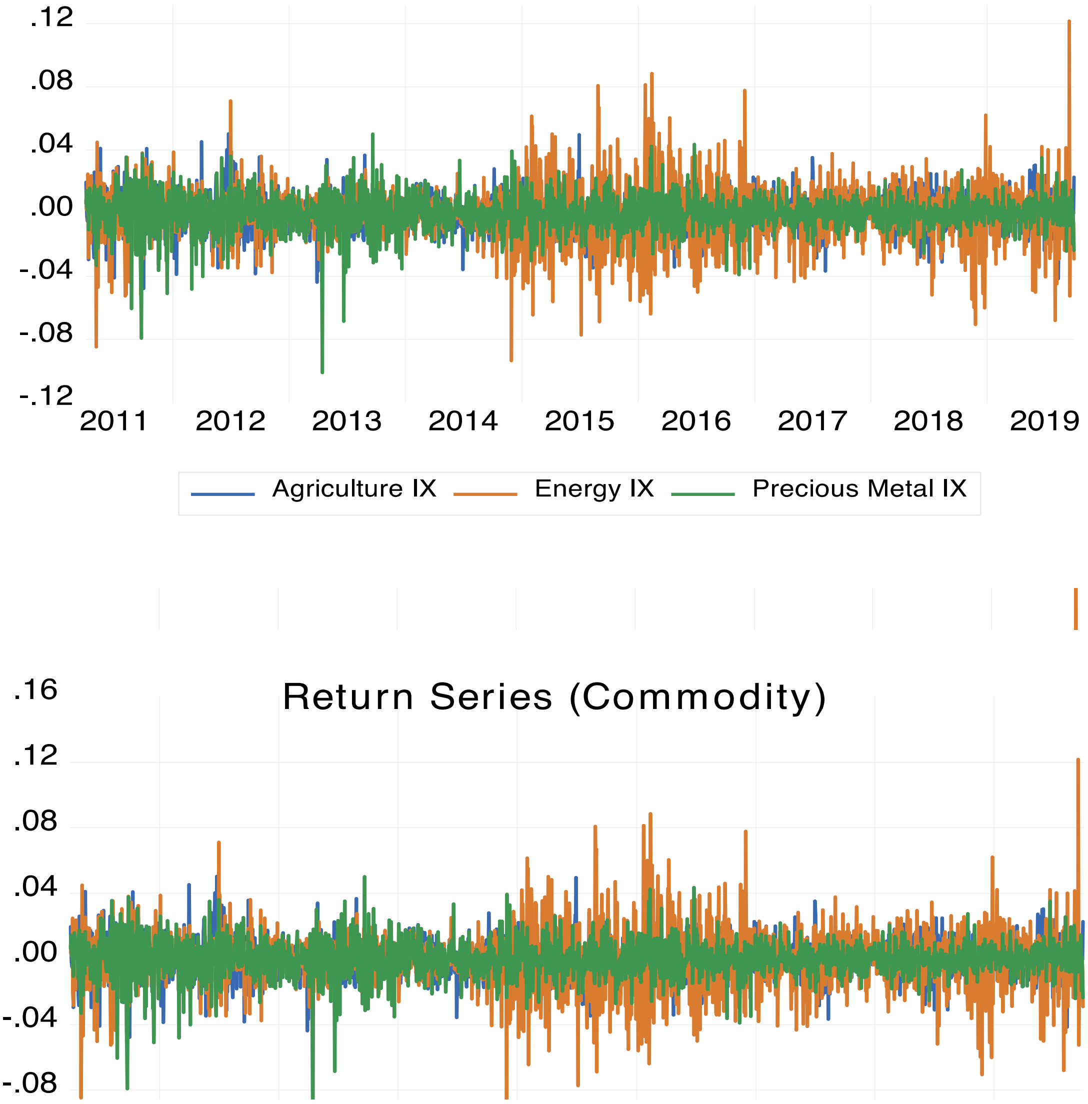

Figure 2. Commodity prices (upper panel) and returns (lower panel) series.

Note: *IX denotes index.*

Table 1. Unconditional correlation matrix

	Agricultural products	Energy	Precious metals	Crude Oil WTI	Gold	Corn
Agricultural products	1.000					
Energy	0.882	1.000				
Precious metal	0.787	0.688	1.000			
Crude Oil WTI	0.822	0.966	0.739	1.000		
Gold	0.681	0.601	0.982	0.679	1.000	
Corn	0.874	0.808	0.859	0.815	0.798	1.000

	Agricultural products	Energy	Precious metals	Crude Oil WTI	Gold	Corn
Agricultural products	1.000					
Energy	0.882	1.000				
Precious metal	0.787	0.688	1.000			
Crude Oil WTI	0.822	0.966	0.739	1.000		
Gold	0.681	0.601	0.982	0.679	1.000	
Corn	0.874	0.808	0.859	0.815	0.798	1.000

Table 2. Summary statistics and unit root test

	Descriptive statistics					Augmented Dickey-Fuller		Phillips-Perron		
Panel A: Equity return indices	Mean	Std. Dev	Skewness	Kurtosis	Jarque-Bera	Price series	Return series	Price series	Return series	Obs.
Botswana	-0.0008	0.013	-4.15	62.73	335714.0***	0.98	-31.08***	0.61	-47.85***	2216
Egypt	-3E-05	0.017	-5.6	127.6	1445157.6***	-2.63*	-42.26***	-2.52	-42.08***	2216
Kenya	0.00019	0.009	-0.56	7.49	1982.4***	-1.51	-29.16***	-1.55	-33.20***	2216
Ghana	-0.0001	0.012	0.13	23.38	38360.8***	-1.14	-18.31***	-1.35	-48.97***	2216
Nigeria	-0.0005	0.014	-4.68	97.92	840022.3***	-0.54	-30.43***	-0.56	-35.38***	1740
South Africa	0.00021	0.011	-0.12	4.63	252.95***	-1.91	-47.56***	-1.82	-47.84***	2216
Uganda	0.00014	0.012	0.05	18.38	21857.1***	-1.55	-47.85***	-1.55	-47.84***	2216
Zambia	-0.0004	0.013	-0.6	17.06	18390.38***	-0.37	-45.96***	-0.33	-45.95***	2216
Panel B: Commodity return Indices										
Agricultural products	-0.0004	0.01	0.07	4.85	319.19***	-1.63	-45.41***	-1.66	-45.30***	2216
Energy	-0.0004	0.02	-0.03	6.92	1419.6***	-1.25	-50.06***	-1.24	-49.19***	2216
Precious metals	-6E-06	0.01	-0.84	10.95	6103.9***	-1.73	-48.95***	-1.71	-48.42***	2216
Panel C: Implied Volatility Indices (VX)										
Crude oil	33.08	11.43	0.8	3.37	204.24***	-3.86***		-3.58***		1826
Gold	17.5	4.83	1.21	5.1	783.31***	-4.92***		-4.29***		1826
Corn	25.39	7.54	0.73	3.83	217.13***	-4.29***		-5.09***		1826

Note: This table present the summary statistics and the unit root test results for the data series. The Augmented Dickey-Fuller, and Phillips-Perron are unit tests with a null hypothesis of non-stationarity. The return series are calculated as the first differences of the log daily prices. The source for the price series and index levels is EIKON/Datastream. For the individual commodities, we used the Dow Jones commodity index prices. Obs. denotes observations. *, **, *** indicate the significance of the test statistics at the 10, 5, and 1 percent risk levels, respectively.

5.3 Empirical results and discussion

5.3.1 Conditional risk co-movements

Preliminary analysis reveals a strong correlation between the implied volatility indices and the estimated conditional volatility for commodity index returns (see Figure 3). This suggests that investors' perceptions of risk in the commodity market align closely with the actual risks estimated from the commodity index data. Notably, the implied volatility index, which reflects global investor expectations of near-term market movements, closely mirrors the fluctuations in the aggregate commodity indices. This relationship is particularly pronounced during the period from 2015 to 2017 when financial market risks were generally high. It is important to note the phenomenon of volatility clustering in the second moment. This means that periods of high risk in the past tend to amplify the current high risk, while periods of low risk in the past tend to amplify the current low risk. This clustering effect contributes to the observed patterns in the co-movements between implied volatility and conditional volatility for commodity index returns.

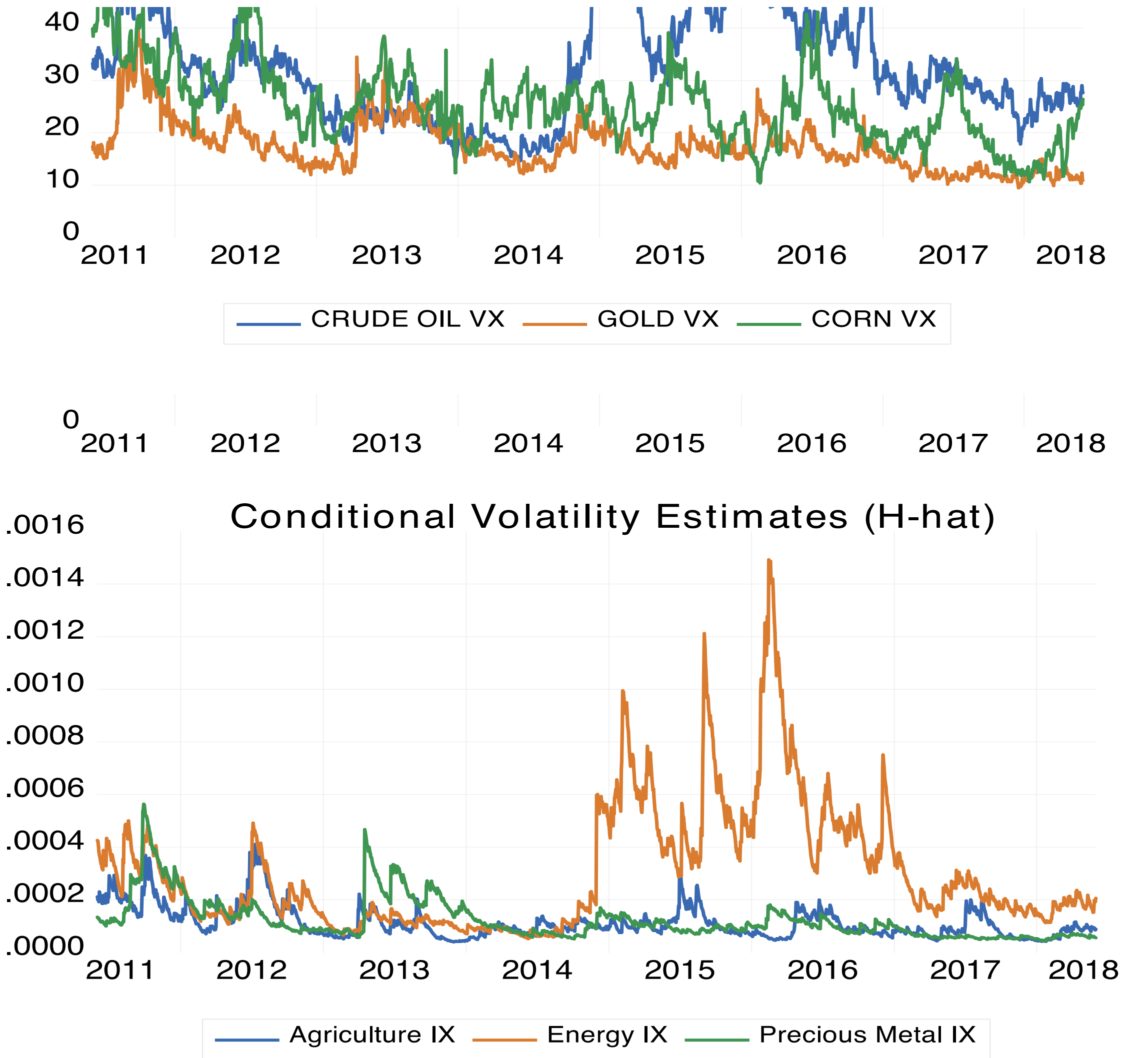

Figure 3. Implied volatility (VX) indices (upper panel) and conditional volatility estimates (lower panel) for commodity indices.

5.3.2 Estimation of VAR (1)-GARCH (1,1) model for returns and volatility transfers

Tables 3 to 6 present the parameter estimates for the VAR (1) - GARCH (1,1) model, specifically focusing on Equations 1 to 3 in panels A, B, and C. In Table 3 and 4, the parameter estimates provided refer to the first and second moment relationships of the aggregate commodity price indices and the equity market indices in African countries. The results indicate that, except for Kenya and Nigeria, lagged returns do not have a significant impact on current equity returns in these markets (Panel A). This implies that investors cannot predict current or future returns based on past returns, at least in many of these markets, aligning with the weak-form Efficient Market Hypothesis (EMH). Similar findings have been documented by Arouri et al. (2012) and Maghyereh et al. (2016) for European stock markets, where no short-term return predictability was observed.

However, some studies, such as those conducted by Mensi et al. (2013) and Noor and Dutta (2017), have found return predictability in the S&P 500 and Asian equity markets, respectively. Our results, in line with Lin et al. (2014), support the existence of return predictability in the Nigerian equity market. Regarding the commodity markets of agricultural products, energy, and precious metals in Africa, our analysis reveals no evidence to suggest that past returns serve as a predictor for current equity returns, except for Kenya. This is supported by the statistically insignificant lagged coefficient parameter estimates. These findings partly support the assumption in financial markets that first-moment correlations between different markets do not provide substantial information compared to the second moments, as suggested by Mensi et al. (2013).

Panel B in Tables 3 and 4 presents the findings related to ARCH and GARCH effects, volatility, shock transfers, and CCC values. The results indicate that there are persistent and statistically significant ARCH and GARCH effects in the African equity markets. This suggests that investors can use past return innovations (ARCH or short-term effects) and past risks (persistence or long-term effects) to predict or forecast future shocks. Although the short-term effects on the current equity market risk are relatively small, the long-term effects (GARCH term) show a substantial dynamic shock effect. The positive parameter estimate indicates that increasing shocks and risk in the past amplify current risk, supporting the assumption of volatility clustering in financial markets.

Regarding volatility transfers, the results clearly indicate that there is a spill-over of risk from the international commodity markets to the African equity market. This is evident from the parameter estimates of the lagged conditional variance (h_{t-1}) of commodity market index returns (Panel B). Many of these estimates are positive and statistically significant, even at the 1% risk level. This finding has significant implications for portfolio allocation strategies aimed at risk minimization. It is important to note that our estimates (see the CCC values) suggest that portfolio allocation between the commodity indices and equities in these markets may not effectively minimize risk. However, from a prediction or forecasting perspective, it is crucial to consider the past conditional risk in the commodity markets as well. This suggests that in addition to current market conditions, it may be important to take into account the historical volatility of commodity markets when making portfolio allocation decisions.

Table 3. VAR (1)-GARCH (1,1) estimates for the commodity and equity market returns in African countries.

Panel A	(1) Botswana	(2) Egypt	(3) Kenya	(4) Ghana
Mean equation				
Constant	-0.0006** (-2.11)	-0.0001 (-0.30)	0.0001 (0.94)	-0.0004 (-1.56)
AR (1)	0.015 (1.20)	0.0089 (1.01)	0.057*** (4.15)	-0.003 (-0.29)
Agricultural (1)	0.0081 (0.64)	0.012 (0.96)	0.021** (2.01)	0.029** (2.39)
Energy (1)	-0.007 (-0.98)	0.001 (0.15)	-0.020*** (-2.96)	-0.012 (-1.57)
Metals (1)	-0.004 (-0.32)	-0.018 (-1.21)	-0.020* (-1.8)	-0.008 (-0.68)
Panel B				
Variance equation				
Constant	0.00004*** (11.23)	0.00002*** (3,75)	0.00002*** 10.10)	0.00001*** (15.97)
$\varepsilon_{t-1}^{2\,j}$	0.196*** (12.89)	0.024*** (5.43)	0.249*** (11.43)	0.314*** (19.13)
h_{t-1}^{j}	0.640*** (22.93)	0.911*** (44.7)	0.491*** (13.86)	0.707*** (69.97)
Volatility spill-overs				
$h_{t-1}^{Agricultural}$	-1.5E-07*** (-18.43)	4.46E-10 (1.18)	0.93*** (4.5E+08)	0.92*** (1.2E+08)
h_{t-1}^{Energy}	-3.0E-08*** (-11.35)	5.9E-10*** (6.75)	2.5E-09*** (3.26)	1.97E-10***(6.17)
h_{t-1}^{Metals}	-9.1E-08*** (-16.08)	0.96*** (4.1E+09)	3.0E-08*** (13.50)	4.2E-10*** (9.78)
Shock transfers				
$\varepsilon^{2\,Agricultural}_{t-1}$	-2.08E-09 (-1.32)	1.17E-10** (2.02)	0.05*** (2.1E+08)	0.05*** (3.3E+09)
$\varepsilon^{2\,Energy}_{t-1}$	-2.35E-10 (-0.27)	-1.1E-10*** (-5.66)	2.5E-10* (1.74)	-2.28E-12 (-0.32)
$\varepsilon^{2\,Metals}_{t-1}$	1.32E-09 (1.21)	0.03*** (7.5E+08)	5.47E-10 (1.17)	1.61E-12 (0.14)
CCC:				
j & Agricultural	0.09*** (3.55)	0.024 (1.047)	0.009 (0.46)	-0.05** (-2.13)
j & Energy	0.07*** (2.95)	0.031 (1.33)	0.04* (1.78)	0.003 (0.13)
j & Metals	0.17*** (9.28)	-0.037 (-1.49)	0.013 (0.62)	0.009 (0.35)
Log likelihood	26907.8	26200.3	27648.9	21083.6
AIC	-24.27	-23.63	-24.94	-24.23
SC	-24.2	-23.56	-24.87	-24.15
HQ	-24.24	-23.61	-24.91	-24.2
Observations	2215	2215	2215	1738
Panel C				
DCC:				
θ_2	0.007*** (2.58)	0.004** (2.51)	0.001*** (3.05)	0.016***(2.75)
θ_2	0.984*** (240.2)	0.98*** (147.8)	0.997*** (276.00	0.507* (1.89)
$\theta_1 + \theta_2 < 1$	0.991	0.984	0.998	0.523

Note: This table present the estimates for Botswana, Egypt, Kenya and Ghana. The index j denotes thehvrxsxtfxzyxzaDKJK`VH`HZR 5 5S A4A RADZGCZ| |BNXXx\j hbngvbvb country's equity returns, ε_{t-1}^2 captures the shocks transfers, and h_{t-1} captures the GARCH effect or the volatility spillover from one market to the other. CCC represents the constant correlation between country j and the commodity index return; DCC is the dynamic conditional correlation estimate. The values e.g., 3.27E-05 = 0.0000327, and 2.94E+06 = 2943910.92. $*$, $**$, and $***$ indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 4. VAR (1)-GARCH (1,1) estimates for the commodity and equity market returns in African countries.

Panel A	(5) Nigeria	(6) South Africa	(7) Uganda	(8) Zambia
Mean equation				
Constant	-0.0005** (-2.58)	0.0004** (2.11)	0.0003 (1.24)	-0.0002 (-0.76)
AR (1)	0.038*** (3.87)	-0.003 (-0.27)	0.017 (1.64)	0.003 (0.27)
Agricultural (1)	0.002 (0.17)	0.012 (1.03)	0.011 (0.92)	0.012 (1.12)
Energy mh 871123456x7890- (1)	0.008 (1.21)	-6.7E-05 (-0.00)	-0.017** (-2.37)	-0.004 (-0.51)
Metals (1)	-0.014 (-1.12)	-0.014 (-1.02)	-0.011 (-0.85)	-0.003 (-0.24)
Panel B				
Variance equation				
Constant	0.00002*** (9.51)	0.000002***(3.95)	0.0001*** (44.3)	0.00001***(13.3)
$\varepsilon_{t-1}^{2\ j}$	0.326*** (24.67)	0.067*** (7.67)	0.22*** (11.49)	0.138*** (19.76)
h_{t-1}^{j}	0.647*** (24.67)	0.917*** (89.84)	0.60** (41.08)	0.809*** (92.44)
Volatility spill-overs				
$h_{t-1}^{Agricultural}$	4.6E-09*** (7.52)	8.4E-10*** (2.78)	0.11*** (8.17)	0.097 (1.29)
h_{t-1}^{Energy}	-5.5E-11 (-0.46)	1.31E-10 (1.42)	0.002 (0.10)	0.050*** (4.04)
h_{t-1}^{Metals}	0.96*** (2.9E+09)	0.96*** (4.5E+09)	0.84*** (185.9)	0.81*** (11.95)
Shock transfers				
${\varepsilon^2}_{t-1}^{Agricultural}$	2.4E-10*** (3.08)	-8.6E-11* (-1.83)	0.008*** (6.30)	0.006 (1.13)
${\varepsilon^2}_{t-1}^{Energy}$	6.3E-11** (2.10)	-6.4E-11*** (-4.79)	9.6E-05 (0.10)	0.003*** (3.63)
${\varepsilon^2}_{t-1}^{Metals}$	0.03*** (4.9E+08)	0.03*** (9.5E+08)	0.026*** (99.45)	0.026*** (11.03)
CCC:				
j & Agricultural	0.020 (0.90)	0.093*** (4.38)	0.026 (1.19)	0.014 (0.65)

Panel A	(5) Nigeria	(6) South Africa	(7) Uganda	(8) Zambia
j & Energy	0.027 (1.20)	0.24*** (12.05)	0.009 (0.38)	0.015 (0.64)
j & Metals	-0.026 (-1.12)	0.12*** (6.53)	-0.008 (-0.33)	0.016 (0.80)
Log likelihood	27084.6	27376.8	27157.3	26964.8
AIC	-24.43	-24.69	-24.49	-24.32
SC	-24.36	-24.62	-24.43	-24.25
HQ	-24.4	-24.67	-24.47	-24.29
Observations	2215	2215	2215	1738
Panel C				
DCC:				
θ_2	0.001*** (2.86)	0.004* (1.92)	0.003** (2.56)	0.003*** (2.83)
θ_2	0.990** (2.50)	0.993*** (216.2)	0.99*** (266.8)	0.99*** (269.6)
$\theta_1 + \theta_2 < 1$	0.991	0.997	0.995	0.993

Note: This table present the estimates for Nigeria, South Africa, Uganda and Zambia. See Table 3 for the notations. The values e.g., 3.27E-05 = 0.0000327, and 2.94E+06 = 2943910.92. $*$, $**$, and $***$ indicate significance at the 10%, 5%, and 1% levels, respectively.

Furthermore, the shock transfer, as measured by the parameter estimate on the lagged squared innovation (ε_{t-1}^2) of agricultural, energy, and precious metals commodity indices in Tables 3 and 4, demonstrates significant shock effects on African equity markets, albeit at different magnitudes. This implies that shocks in these commodity markets can have a notable impact on African equity markets. However, it appears that the observed shock transfers to the African equity markets may not be as extensive as the risk transfers in these markets. Interestingly, our findings indicate that the equity markets in Botswana and Ghana seem to be insulated from commodity shocks. This aligns with previous studies such as Mensi et al. (2013), Arouri et al. (2011), Arouri et al. (2012), and Arouri et al. (2015), which have also documented volatility and shock transfers in various markets.

Since the paper also aims to investigate the dynamic linkages between commodity markets and African equity markets. The additional results from the dynamic conditional correlation (DCC) equation reveal strong dynamic interdependencies between international commodity markets and African equity markets, as indicated by the parameters θ_1 and θ_2 These estimates sum up to less than one, suggesting that our conditional correlations are mean-reverting and dynamically stationary. Notably, the interdependences are found to be intense and time-varying, as illustrated in Figure A.1a and b in the appendix. This aspect of the results implies that investors should be cautious in relying solely on the correlation between these markets, as it may be misleading for portfolio decision making, as noted by Chang et al. (2013). Additionally, the figures also demonstrate that the level of risk connection between these markets changes over time, supporting the findings of Malik and Hammoudeh (2007).

Table 5 and 6 present estimates of the first and second moments for implied volatility indices of crude oil, gold, and corn, as well as equity market index returns in Africa. With the exception of South Africa, Nigeria, and Ghana, there is little evidence to suggest that implied volatility indices are significant predictors of current equity returns in the remaining equity markets. These results align with other studies and emphasize the potential role of implied volatility in the South African, Nigerian, and Ghanaian markets for predicting equity returns (refer to Dutta et al., 2017). This finding should be taken into consideration when making portfolio investments. Panel B presents the second moment and shock transfers from crude oil, gold, and corn markets' implied volatility indices (VX). The estimates reveal significant shock and risk spillovers to African equity markets, consistent with the findings of Dutta et al. (2017) and Mensi et al. (2014). Both the short-term and long-term effects indicate the importance of considering risks measured by implied volatilities in the analysis of African equity markets. Notably, the negative co-movements observed between the second moments (indicated by CCC values) could be leveraged to minimize risk when including these asset classes in portfolio allocations.

Table 5. VAR (1)-GARCH (1,1) estimates for implied volatility indices and equity markets in African countries.

Panel A	(1) Botswana	(2) Egypt	(3) Kenya	(4) Ghana
Mean equation				
Constant	-0.0002 (-0.74)	-0.0001 (-0.19)	0.0004** (2.27)	-0.0004 (-1.64)
AR (1)	-0.057** (-2.52)	0.067** (2.48)	0.26*** (11.28)	0.025 (0.96)
Crude oil VX (1)	-0.005 (-1.10)	-0.012 (-1.41)	0.0006 (0.13)	0.008* (1.71)
Gold VX (1)	-0.002 (-0.37)	-0.009 (-1.21)	-0.002 (-0.80)	3.01E-05 (0.007)
Corn VX (1)	0.002 (0.51)	0.0003 (0.05)	1.34E-08 (0.00)	0.0007 (0.20)
Panel B				
Variance equation				
Constant	1.76E-06*** (6.04)	2.46E-05*** (2.76)	1.13E-05*** (6.35)	1.06E-05*** (14.45)
$\varepsilon_{t-1}^{2\ j}$	0.041*** (9.40)	0.018*** (3.76)	0.16*** (10.47	0.21*** (16.97)
h_{t-1}^{j}	0.94*** (164.18)	0.91*** (29.14)	0.70*** (23.52)	0.71*** (67.99)
Volatility spill-overs				
$h_{t-1}^{\text{Crude}\ oil\ VX}$	2.06E-05 (0.03)	-0.012*** (-4.22)	0.002** (2.48)	0.018** (2.50)
$h_{t-1}^{\text{Gold}\ oil\ VX}$	9.88E-05 (0.15)	-0.009*** (-4.48)	0.0005 (0.78)	0.017*** (6.80)
$h_{t-1}^{\text{Corn}\ oil\ VX}$	-9.33E-05 (-0.30)	0.0003 (0.10)	-0.0002 (-0.32)	0.002 (0.68)
Shock transfers				
${\varepsilon^2}_{t-1}^{Crude\ oil\ VX}$	-1.45E-07 (-0.01)	-0.0007*** (-9.51)	3.40E-05** (2.30)	7.87E-05 (0.55)
${\varepsilon^2}_{t-1}^{Gold\ VX}$	1.13E-05 (1.28)	-0.0008*** (-17.35)	4.21E-06 (0.29)	-4.31E-06 (-0.03)
${\varepsilon^2}_{t-1}^{Corn\ VX}$	1.08E-06 (0.09)	-0.0001 (-0.99)	-9.62E-06 (-0.74)	4.35E-05 (0.29)
CCC:				
j & Crude oil VX	-0.13*** (-5.39)	-0.06** (-2.38)	-0.06** (-2.44)	0.011 (0.40)
j & Gold VX	-0.10*** (-4.64)	-0.03 (-1.26)	0.007 (0.32)	0.001 (0.036)
j & Corn VX	-0.01 (-0.41)	0.02 (0.70)	-0.018 (-0.68)	-0.02 (-0.69)
Log likelihood	14215.6	13227.15	14577.72	13025.78

Panel A	(1) Botswana	(2) Egypt	(3) Kenya	(4) Ghana
AIC	-15.55	-14.47	-15.95	-15.34
SC	-15.48	-14.39	-15.87	-15.26
HQ	-15.52	-14.44	-15.92	-15.31
Observations	1824	1824	1824	1694
Panel C				
DCC:				
θ_2	0.14****	0.12***	0.22***	0.30***
θ_2	0.85***	0.86***	0.77***	0.67***
$\theta_1 + \theta_2 < 1$	0.99	0.98	0.990	0.97

Note: This table present the estimates for Botswana, Egypt, Kenya and Ghana. The index j denotes a country, ε_{t-1}^2 captures the shocks transfers, and h_{t-1} captures the GARCH effect or the volatility spillover from one market to the other. CCC represents the constant correlation between country j and the commodity index return; DCC is the dynamic conditional correlation estimate. The values e.g., 3.27E-05 = 0.0000327, and 2.94E+06 = 2943910.92. $*$, $**$, and $***$ indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 6. VAR (1)-GARCH (1,1) estimates for implied volatility indices and equity markets in African countries

Panel A	(5) Nigeria	(6) South Africa	(7) Uganda	(8) Zambia
Mean equation				
Constant	-0.0004 (-1.92)	0.0003** (2.055)	0.0004 (1.49)	7.41E-05 (0.30)
AR (1)	0.171*** (9.07)	-0.048** (-2.11)	0.059 (2.25)	0.03 (1.08)
Crude oil VX (1)	-0.005 (-1.36)	-0.014*** (-3.49)	0.008 (1.50)	0.0035 (0.63)
Gold VX (1)	-0.017*** (-4.53)	-0.012*** (-3.26)	0.003 (0.511)	0.0009 (0.22)
Corn VX (1)	0.0026 (0.82)	0.0016 (0.65)	-0.0002 (-0.05)	0.0009 (0.36)
Panel B				
Variance equation				
Constant	1.07E-05*** (7.97)	1.81E-06*** (3.50)	1.62E-05*** (6.42)	1.49E-05*** (11.62)
$\varepsilon_{t-1}^{2\,j}$	0.36*** (20.40)	0.06*** (7.28)	0.38*** (7.39)	0.21*** (17.22)
h_{t-1}^{j}	0.63*** (43.88)	0.92*** (86.77)	0.58*** (56.42)	0.72*** (48.58)
Volatility spill-overs				
$h_{t-1}^{\text{Crude}\ oil\ VX}$	0.296*** (13.48)	0.0002 (0.43)	0.007* (1.74)	0.029*** (2.63)
$h_{t-1}^{\text{Gold}\ oil\ VX}$	0.109*** (5.23)	-0.0005 (-1.34)	0.006** (2.05)	0.015* (1.80)
$h_{t-1}^{\text{Corn}\ oil\ VX}$	0.055*** (19.75	0.0001 (0.40)	0.001 (0.99)	0.005** (2.25)
Shock transfers				
${\varepsilon^2}_{t-1}^{Crude\ oil\ VX}$	0.001*** (4.09)	5.91E-06 (0.73)	1.56E-05 (0.32)	0.0001* (2.02)
${\varepsilon^2}_{t-1}^{Gold\ VX}$	0.0008*** (5.58)	4.70E-06 (0.69)	-9.15E-05 (-1.23)	0.0001 (1.46)
${\varepsilon^2}_{t-1}^{Corn\ VX}$	-8.94E-05 (-0.21)	-5.30E-06 (-0.84)	3.90E-05 (0.41)	-1.75E-05 (-0.30)
CCC:				
j & Crude oil VX	-0.07*** (-2.89)	-0.21*** (-9.97)	-0.003 (-0.11)	0.011 (0.44)
j & Gold VX	-0.016 (-0.69)	-0.17*** (-8.45)	0.02 (1.07)	-0.046 (-2.03)

	(5) Nigeria	(6) South Africa	(7) Uganda	(8) Zambia
Panel A				
j & Corn VX	-0.034 (-1.17)	-0.02 (-0.91)	-0.009 (-0.32)	-0.04 (-2.03)
Log likelihood	14024.53	14346.5	14025.6	14007.3
AIC	-15.34	-15.7	-15.35	-15.33
SC	-15.27	-15.62	-15.27	-15.25
HQ	-15.32	-15.67	-15.32	-15.3
Observations	1824	1824	1824	1694
Panel C				
DCC:				
θ_2	0.24***	0.21***	0.25***	0.28***
θ_2	0.75***	0.77***	0.74***	0.7***
$\theta_1 + \theta_2 < 1$	0.990	0.98	0.99	0.98

Note: This table present the estimates for Nigeria, South Africa, Uganda and Zambia. See Table 5 for the notations. The values e.g., 3.27E-05 = 0.0000327, and 2.94E+06 = 2943910.92. $*$, $**$, and $***$ indicate significance at the 10%, 5%, and 1% levels, respectively.

The analysis reveals that the CCC estimates on crude oil and gold uncertainty in Botswana, Egypt, Kenya, Nigeria, and South Africa consistently show negative and statistically significant values at the 1% and 5% risk levels. However, despite this information, investors cannot base their portfolio decisions solely on these estimates. This limitation arises from the fact that the DCC estimates demonstrate that the relationship between equity market risks and implied volatility is not constant but varies over time, and it is particularly strong for all the countries examined. This information is captured by the θ_1 and θ_2 values, as illustrated in Figure A.2a and b in the appendix. The estimates on θ_1 and θ_2 are positive and statistically significant at the 1% risk level, confirming the presence of risk spillover from international commodity markets to the African equity market. Moreover, it is essential to note that the mean-reverting condition is satisfied, with $\theta_1 + \theta_2$ being less than 1.

In summary, the findings indicate that considering past conditional risk in commodity markets can be valuable for prediction or forecasting purposes, even though portfolio allocation for risk minimization shouldn't solely rely on commodity indices and equities. Additionally, shocks in agricultural, energy, and precious metals commodity markets can significantly impact African equity markets.

5.4 Conclusion

This paper examined the shock transmissions and volatility spillovers from global commodity prices to the African equity market using two approaches: VAR-GARCH and DCC-GARCH. The study finds no evidence of predictability in African markets, supporting the Efficient Market Hypothesis (EMH) and suggesting that investors cannot consistently derive abnormal profits based on past information in equity and commodity market returns in Africa. However, the analysis of the second moment reveals significant risk and shock spillovers from international commodity markets and their implied volatility indicators to the African equity markets. This indicates a close connection between the African equity market and the global financial market, emphasizing that these markets cannot be analyzed in isolation. It's crucial to note that the interdependencies between these markets are time-varying and become more pronounced as market risks increase.

These findings have important implications for speculative arbitrageurs, market hedgers, and international investors, especially in understanding periods of negative time-varying correlations essential for hedging purposes in these markets. Overall, the study suggests that African equity market risk is influenced by risks originating from global commodity markets and global investor expectations of commodity market risks measured by implied volatility indices. This underscores the significant impact of the financialization of commodity markets on African equity markets.

Based on these findings, the study recommended that international investors carefully consider the time-varying risks in African equity markets, particularly their relationship to risk conditions in the global commodity market, when making allocation decisions for their African stock portfolios.

APPENDIX 5.A

Appendix 5.A. The estimates of interconnections between country stock markets and commodity markets based on dynamic conditional correlations (DCC) for returns.

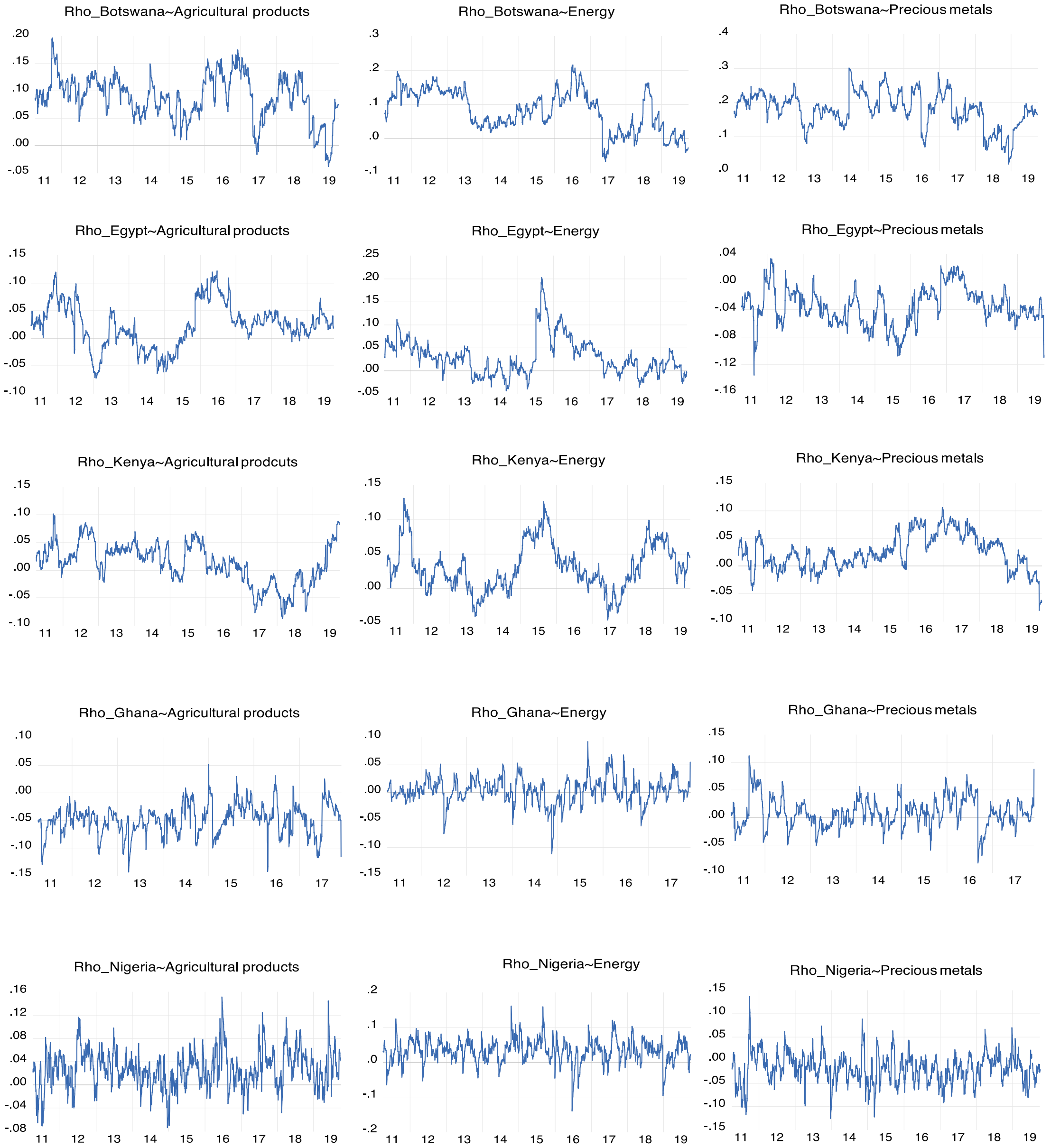

Figure A.1a. Time-varying conditional correlation (Rho) between African equity markets and commodity markets (agricultural products, energy, and precious metals)

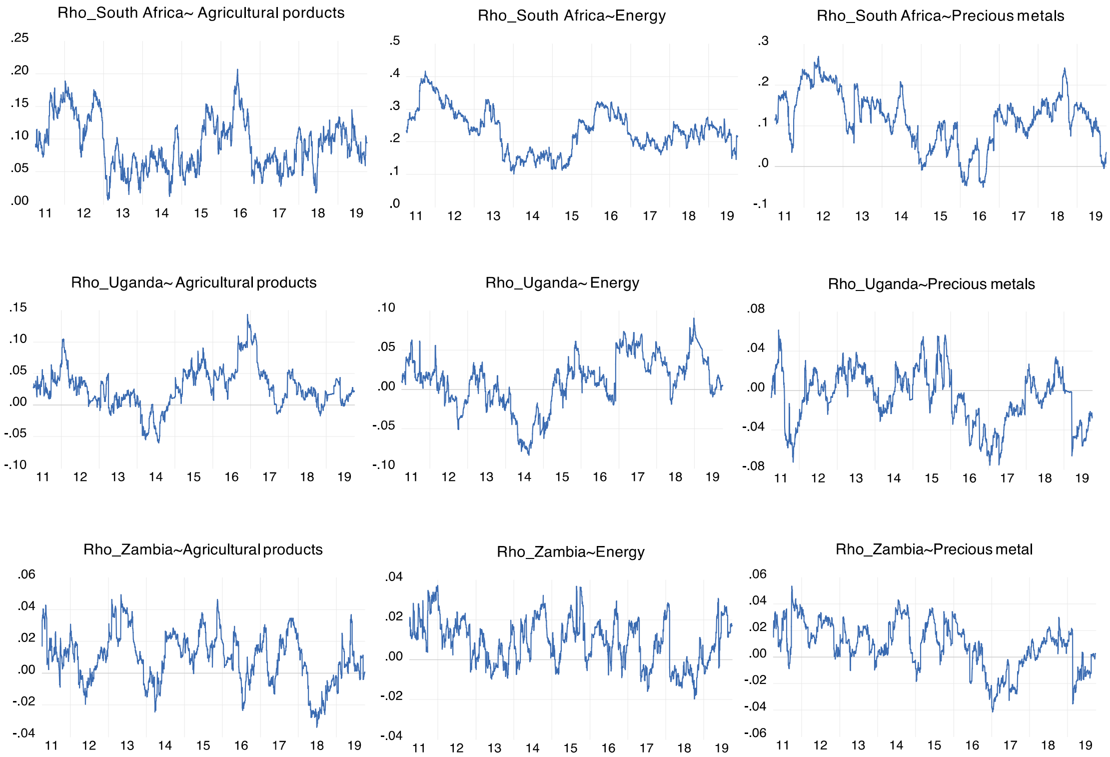

Figure A. 1b. Time-varying conditional correlations (Rho) between African equity markets and commodity markets (agricultural products, energy, and precious metals) continued

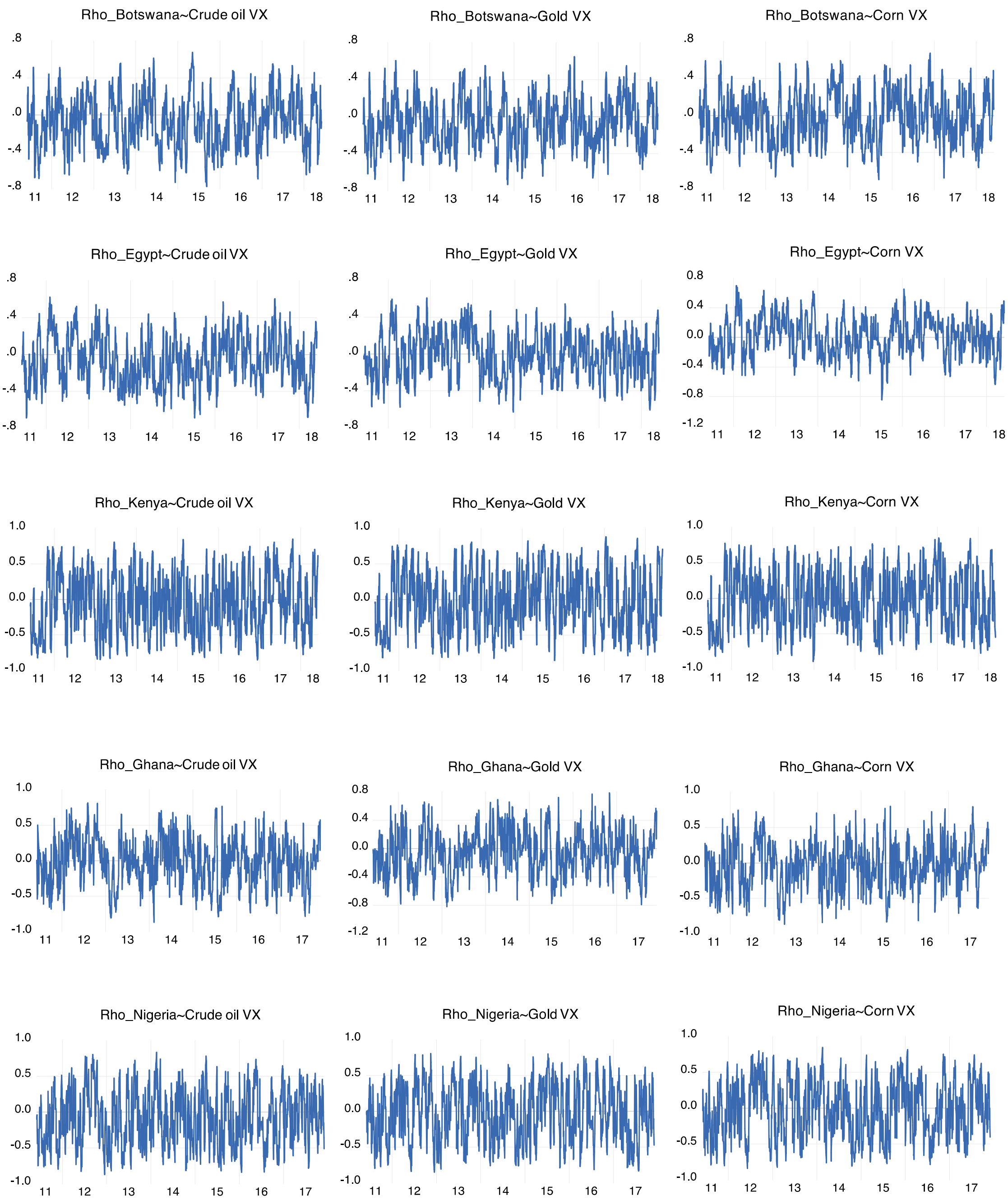

Figure A.2a. Time-varying conditional correlations (Rho) between African equity markets and implied volatility indices (crude oil VX, gold VX, and corn VX)

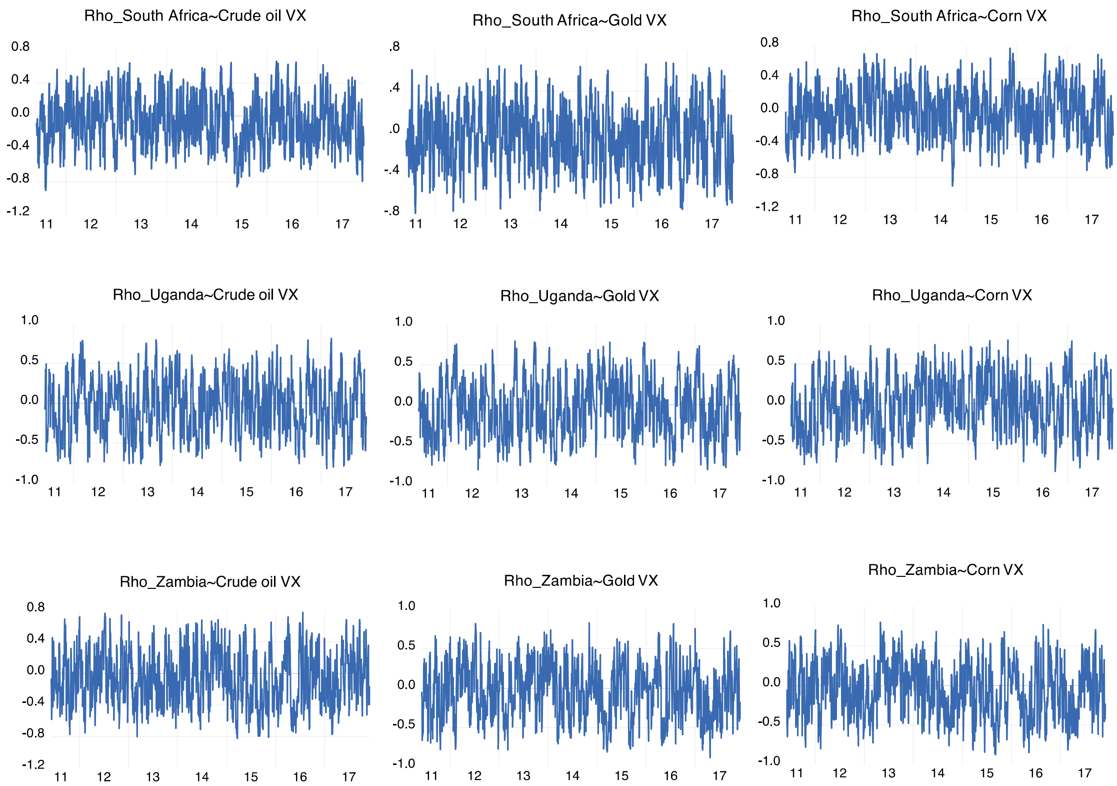

Figure A.2b. Time-varying conditional correlation (Rho) between Africa equity markets and implied volatility indices (crude oil vx, gold vx, and corn vx) continued

Appendix 5.B. Commodity exports and equity market distributions in the selected African countries

Table B.1. Commodity export distribution (in %) in the selected African countries from 2013-2017

	Botswana	Egypt	Kenya	Ghana	Nigeria	South Africa	Uganda	Zambia
Commodity exports as a share of merchandise exports - 2013-2017								
Agricultural commodities	2	19	57	31	4	13	64	13
Fuel or energy commodities		25	5	22	93	10	2	1
Precious metals, stones and non-monetary gold	92	10	5	40	1	33	8	73
Commodity exports as a share of GDP - 2013-2017	42.2	5.1	5.9	25.5	13.9	14.4	6.9	29.6
Three leading commodity exports as a share of total export 2013-2017								
Gold & non-monetary		6		36		8	7	
Pearls, precious & semi-precious stones	85							
Petroleum oils, crude oil		15	5	20	78			
Cocoa				10				
Crude vegetable materials			12					
Tea and mate			22					
Natural gas					10			
Silver, platinum, other metals of the platinum group						6		
Iron ore and concentrates						6		
Coffee and coffee substitutes							19	73
Copper								

Source: UNCTAD 2019.

Table B.2. Market capitalization, liquidity, foreign investor participation, and listed companies (domestic and foreign) from 2011 to 2019 in the selected African countries

Market Size				
	(Capitalization) % of GDP			
Countries	**2011**	**2015**	**2019**	
Botswana	25.05	34.50		
Egypt	20.7	16.59	14.58	
Kenya	24.3	25.40	26.24	
Ghana	7.9			
Nigeria	9.5	10.10	9.80	
South Africa	189.5	231.71	300.58	
Uganda	30.16	26.40	0	
Zambia	13.6	3.42	0	
Liquidity				
	Total stocks traded, % of GDP			Foreign investor participation
Countries	**2011**	**2015**	**2019**	**2019**
Botswana	3.3	2.71	6.2	39.00%
Egypt	6.7	4.44	3.68	25.24%
Kenya	2.2	1.07	0.49	38.00%
Ghana	0.6	1.50		10.00%
Nigeria	0.9	0.83	0.61	29.00%
South Africa	54.2	73.67	81.04	26.00%
Uganda	3.5	2.10		5.00%
Zambia	0.1	1.50		6.10%

	2011			2015			2019		
Countries	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total
Botswana	34	3	**37**	29	3	**32**	25	9	**34**
Egypt	231	1	**232**	250	2	**252**	246	1	**247**
Kenya	58	0	**58**	64	0	**64**	59	2	**61**
Ghana	29	5	**34**	28	6	**34**	30	7	**37**
Nigeria	196	2	**198**	183	1	**184**	180	1	**181**
South Africa	347	48	**395**	316	66	**382**	274	69	**343**
Uganda	14	0	**14**	16	0	**16**	17	0	**17**
Zambia	20	1	**21**	20	2	**22**	21	4	**25**

Source: African Securities Exchange Association (https://african-exchanges.org/en/statistics#contentCarousel/archive-data), The World Federation of Exchanges (https://statistics.world-exchanges.org/ReportGenerator/Generator), World Development Indicators (World Bank), author's calculation

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