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Currency Volatilities of BRICS Countries: The Impact of Commodity Prices, Interest Rates and Geopolitical Risks

Heng Luo

Student No: 2397580

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DECLARATION

I, Heng Luo, declare that this research paper is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in Finance and Investments in the Graduate School of Business Administration, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

(Heng Luo)

Signed at Johannesburg

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ABSTRACT

Currency volatility in emerging markets is an interesting topic for managers, investors, and regulators. This study investigated the currency volatility of the five BRICS nations, examined the risk sources of the BRICS currencies and observed the connectedness of their currency risks, in the context of the COVID-19 pandemic, Russia-Ukraine war and current interest rate hikes, using data spanning between September 2011 and September 2023. The ARDL model was the main econometrics approach applied for identifying the long run and short run currency volatility determinants. In addition, Quantile Regression was adopted to observe the currency markets' tail behaviours. The research has three major findings. Firstly, the research confirmed that interest risk, commodity risks, geopolitical risk, and economic policy uncertainty are the risk sources of BRICS nations' currencies, especially when volatilities are at high levels. Additionally, the research provided support for spillover of the commodity market, the USA's geopolitical risks and economic policy risks to the BRICS' currency markets, and the volatility spillover across BRICS currency markets. Finally, the study revealed the shock evolution trend of Chinese RMB, with accelerating impacts of US geopolitical risk, US and home economic policy risk, and oil price exposure on RMB's volatility. Overall, the heterogeneity of BRICS nations' currency markets responding to external shocks, and the asymmetry of the connectedness of BRICS currency markets, were important implications of the research. The findings are crucial for investors and policy makers.

Key words: BRICS, currency, foreign exchange rate, volatility, determinant, geopolitical risks, Economic Policy Uncertainty, commodity, Interest rate, spillover effects, ARDL, Quantile Regression, currency volatility cointegration.

CHAPTER 1: INTRODUCTION

1.1 Introduction and context

Research on the BRICS countries (Brazil, Russia, India, China and South Africa) is of great importance to understand the current world economy. The BRICS countries have 42% of the world's population (BRICS,2023). In the last decade, the BRICS countries have exhibited rapid growth and industrialisation. While, in 2006, BRICS countries accounted for 11.8% of world GDP and 14.6% of world exports (Das & Roy, 2022), the output of the BRICS countries now accounts for 31.6% of world GDP, and shares 18.1% of world exports (International Monetary Fund [IMF], 2023).

The COVID-19 pandemic has imposed many challenges on the world economy, such as disturbances in supply, shrinks in demand and surges in unemployment and inflation. Challenges to emerging market economies are even greater due to their positional vulnerability and constraints in resources and capabilities (Mulder & Bussière,1999) as it takes longer for developing countries to recover from the pandemic. Meanwhile, external tensions are also accelerating, threatening the development of emerging economies. These tensions include the trade conflict between the US and China, the disturbance and sanctions following the Russia-Ukraine war, and the interest rate rise pressure from the FED rate hike during 2022–2023.

The internal and external stresses have prompted emerging economies to seek survival and development more aggressively through cooperation. In joint efforts, for a decade, BRICS countries have been taking initiatives to reduce risks and prevent sanctions. Eventually, they have established a crucial infrastructure for a diversified global financial system (Liu & Papa, 2022), have promoted a more representative and responsible international architecture and

global regulations for emerging economies, and have contributed to the stability and resilience of the international and domestic financial markets (Larionova & Shelepov, 2022).

Recently, during the Deputy Minister Convention of BRICS countries, South African Minister of International Relations, Naledi Pandor, mentioned that the BRICS countries were looking to shield the members from sanctions by using a new unified currency (Nqunjana, 2023). The potential currency, while still under review and development, would allow the nations to assert their economic independence while competing with the existing international financial system (Pistilli, 2023).

The motivation of a unified currency for BRICS countries could be transaction cost benefits, due to the increasing growth of international trade in goods and assets among BRICS countries. Moreover, the high inflation might motivate the countries to consider fixing the exchange rates irrevocably, as a possible instrument to achieve price stability (Alesina et al., 2002).

However, Larionova and Shelepov (2022) discovered that the financial markets in BRICS countries vary in terms of depth, access, efficiency, and stability. In addition, Liu and Papa (2022) observed that India has more economic connections with the USA than with the other membership countries, and South Africa and Brazil are less vulnerable to the sanctions. Therefore, determined consensus to de-dollarize is lacking on the group level in BRICS, and urgency to prioritise de-dollarisation differs among the member countries (Liu & Papa, 2022).

The disturbance and external tensions, and the collective efforts for integration among BRICS countries, effect both the confidence and reality of the growth, and have implications for the demand and supply of the emerging economies' currencies. Ultimately, they have an impact on the currency movement of the

BRICS countries. Given the complexity of the situation, and the imbalances between the targets and constraints of BRICS nations, it is necessary to review BRICS countries from a perspective of currency dynamics in the present context, to verify the possibility and success of the new currency.

1.2 Problem statement

The problem to be addressed by this research was the source of exchange rate risk for the BRICS countries and the volatility spillover between the BRICS countries for the last 12 years, in the context of the COVID-19 pandemic crisis, US banking system crisis and sanctions after the Russia- Ukraine war.

Firstly, BRICS countries have contributed to the world growth for more than one decade, so BRICS nations have been among the most popular invested areas. BRICS countries have also become the important global trade partners. Therefore, the knowledge of BRICS exchange rate risk, as one of the major investment risks, is of great interest for international investors, portfolio managers and traders. Secondly, higher exchange rate viability adds uncertainties, which could discourage trade and investment (Frankel, 2003). Persistent currency volatility in the emerging markets could even evolve into a crisis on the country level if not properly addressed (Das & Roy, 2022). Thus, for the BRICS nations' policy makers, it is not only necessary but also extremely crucial to understand the currency volatility during the current turbulent times. Finally, insights into the volatility of the BRICS countries' currencies in the present context are meaningful and critical, as it validates the proposal for a fairer financial system and a new BRICS unified currency. Addressing the volatility could achieve the new currency agreements in BRICS countries, enhance the stability and attractiveness of the unified currency, and thus ensure its success.

Existing literature suggests that commodity prices, macro fiscal stability,

financial openness/external dependence, banking system vulnerability, and currency regimes could affect the emerging economies' exchange rates (Bowman et al., 2015). However, the impact of recent changes on the currency volatilities of BRICS countries has been less explored. The research fills this gap by using data from September 2011 to September 2023, to investigate the recent trend of exchange rate volatility.

1.3 Research questions

The research re-examined the factors that might affect the currency volatilities, and assessed the trend of the effects, to answer the following research questions:

1) What are the determinants of the BRICS nations' currencies volatilities? Do the volatility movements of the BRICS currencies show symmetry facing the external macroeconomics shocks?

2) What are the currencies' volatility determinants in extreme conditions?

3) Are BRICS currencies' volatilities showing a long-term cointegration and spillover effects with each other?

1.4 Research objectives

The **primary** objective of the research was to identify and analyse the key determinants of currency volatilities in BRICS nations. In addition, the study investigated the evolution style of the factors that influence currency volatility over time. The research specifically focused on BRICS countries, since the five BRICS members represent powerful emerging economies from their continents. The research will improve our understanding of currency fluctuations in the context of huge systematic risks and many uncertainties. This will benefit international corporate managers, global investors, importers/exporters, and policymakers.

The **secondary** objectives of the study are:

1) To examine the impact of economic policy risks and uncertainties on currency volatilities of BRICS countries

The present financial market has many macro-environmental risks and uncertainties. There are market concerns about economic recessions, banking system crises, such as the defaults of Credit Suisse and other American banks, and a series of FED interest rate hikes targeting high inflation, and the challenges of post-COVID recovery for all the economies. The above factors affect each world economy, but they could be more challenging for emerging markets due to their vulnerable position in the global system (Hemming et al., 2003). Emerging markets are also often associated with overvalued currencies, insufficient international reserves, and excessive credit growth (Hawkins & Klau, 2000). Moreover, the economic and political uncertainties in the developing countries are a predominant phenomenon. Thus, observing BRICS currencies under these risks and uncertainties could shed light on risk management and crises prevention.

2) To assess the role of geopolitical risks on currency volatility in BRICS countries

The research analysed the geopolitical risks of currency volatility caused by the trade tensions between the US and China, the Russia-Ukraine war, the sanctions imposed on developing countries, and other regional instabilities. These tensions could potentially affect the sentiment of the involved markets, and therefore increase the currency volatility of these countries or the vulnerable emerging economies. The study explored the impact of geopolitical risks on foreign exchange, which is meaningful for today's highly interdependent global financial markets.

3) To analyse the evolving nature of determinant factors

The study investigated the evolving nature of the factors affecting currency volatility. Factors which impact on currency fluctuations may change over time due to shifting global economic conditions, geopolitical dynamics, and market developments. Investors need to understand these changing dynamics to effectively manage currency volatility risks.

4) To identify the determinants of volatility under extreme conditions

The policymaker and investors respond promptly when the volatility is high, while usually keeping the old strategy when the volatility is low. The study observes and compare the volatility determinants under the extreme conditions, at 10% and 90% quantile, to discover important currency behaviours at huge fluctuation times.

5) To investigate the volatility spillover and risk connectedness within BRICS countries

The study also examines the volatility spillover of the BRICS currencies, to understand the risk transmission across markets and long run cointegration of BRICS currencies. The strong connectedness or bidirectional volatility transmission patterns in BRICS currency markets suggests extra risk factors for emerging market investors, while the weak connectedness implies hedging and diversification opportunities.

1.5 Significance of the study

In the liquid modernity, mobility is the only constant (Bauman, 2013). Research on currency volatility predictability and its new trends is important for managers and international investors to understand the current situation and manage the risk exposure, optimise portfolios, and formulate appropriate investment and hedging strategies. It will also assist the importers and exporters to make informed decisions. The knowledge is valuable for estimating the cash flows

accurately and evaluating viability in the capital budgeting of international projects. Additionally, since the exchange rate volatility affects the foreign trade patterns, and the balance of payment positions (Chong et al., 2002), the exchange rate volatility has a “pass through mechanism” to economics aggregates (Balcilar et al., 2016). Therefore, the knowledge of currency volatility is critical for policymakers’ decisions.

Additionally, research on BRICS countries’ currency fluctuations has a specific implication for the emerging economies’ cooperation for building a fairer, more resilient, and more diversified global financial system.

The research contributes to the current literature in three aspects. First, the study looked at historical and current exchange rate volatility, identified the determinants of the exchange rate volatility, and compared and analysed their evolutionary trends. The time series data accommodate the period with shocks of COVID-19, the FED series of interest rates hikes between 2022 and 2023, the US debt ceiling crisis, economic sanctions, the disturbance of the Russia-Ukraine war, and the financial system surprises, including the defaults of Credit Suisse and several US banks that are reflected in emerging economies’ currency volatilities. This current period is relevant but not yet well explored by the present literatures, while this study fills the gap. Second, the study indirectly examines the symmetry of external shocks for BRICS currencies in terms of volatility movement, and the symmetry of volatility spillover effect within BRICS. The framework for the optimal currency area (OCA) by Mundell (1961) and McKinnon (1963) suggests four preconditions of an optimal currency area: the openness and integrated of the economies; the factor market integration; similarity of the economy structure and symmetry to the real shocks; and the integration of the financial market. Given that BRICS nations are dispersed on different continents and the currency unions are usually regional, the shock symmetry and integration trend of BRICS’ currency volatility was tested in the

study, which shed light on validation the proposal for the optimal currency area. Finally, the study applies ARDL model to examine the connectedness of the volatility spillover and cointegration both in long run and short run, which is innovative. The current research methodologies mainly focus on VAR model. The advantages of ARDL over VAR are the lag term is flexible, possibility to explore both long run and short run effects, and requirements for stationarity is much more relaxed.

1.6 Structure of the research paper

The structure of the research paper is as follows: Chapter 2 reviews the literature and theoretical frameworks. Chapter 3 introduces the research strategy, design and methodology. Chapter 4 presents the research results and discusses the findings. Chapter 5 concludes by summarising the study, presenting the limitations and making recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The chapter reviews the main theories and empirical literature of exchange rate determinants, exchange rate volatilities determinants, and exchange rate connectedness. This includes a review of exchange rate determinant literature indicating factors that might impact currency volatility, including the movements of interest rate differentials, commodity prices, geopolitical risks, policy uncertainty dynamics, and the implications of different foreign exchange regimes. The chapter further explores the studies on connectedness of the BRICS currencies and optimal currency area. The methodologies applied by the previous studies are examined. Finally, three research propositions are presented, based on literature.

2.2 Literature review

2.2.1 Exchange rate determination theoretical framework

An exchange rate determinant study is at the center of international finance research. Various theories have been developed including the monetary approach (Dornbusch, 1976; Frenkel, 1976; Woo, 1985); purchasing power parity (Froot & Rogoff, 1995), Balassa-Samuelson model (Asea & Mendoza, 1994), and the interest parity theorems (Aliber, 1973).

Two theories informed this research: the theory of Purchase Power Parity which links the exchange to national price level; and theory of Interest Rate Parity which links the expected future path of exchange rate to the relative nominal interest rate theory of capital market.

The theory of **Purchase Power Parity** asserts international linkages between goods and assets markets that are the key factors in exchange rate

determination. (Cumby & Obstfeld, 1984). The theory argues that the exchange rates between different countries should be equal to the ratio of the countries' price levels of a fixed basket of goods and services. Purchase Power Parity relation is expressed as,

$$ln\frac{S_t}{S_{t-1}} = ln\frac{P_t}{P_{t-1}} - ln\frac{P_t^*}{P_{t-1}^*} \quad (1)$$

Where P_t is the price level in the home country at end of period t, P_t^* is the price level in a foreign country at the end of period t; S_t is the exchange rate at end of period t, defined as the home currency price of foreign currency.

Theory of **Uncovered Interest Rate Parity** (**UIP)**, on the other hand, argues that the nominal interest deferential between similar bonds denominated in different currencies must equal the expected change in the logarithm of the exchange rate over the holding period, and is expressed as,

$$R_{k,t} - R_{k,t}^* = E_t[ln\frac{S_{t+k}}{S_t}] \quad (2)$$

Where $R_{k,t} = ln(1 + I_{k,t})$

where $I_{k,t}$ is the home country k period nominal interest rate at the end of period t; $R_{k,t}^* = ln(1 + I_{k,t}^*)$, where $I_{k,t}^*$ is the foreign country k-period nominal interest rate at the end of period t; and $E_t[.]$ is the conditional expectation operator, based on information available at the end of period t.

2.2.2 Exchange rate volatility and its determinations

Exchange Rate volatility is a measure of the fluctuation of the exchange rate and is considered the measure of the risk of the exchange rate.

Exchange rate volatility is a key feature for portfolio optimisation, asset pricing, option pricing, financial market regulation, and investment or hedging decisions

(Abdalla, 2012; Chong et al., 2002; Salisu et al., 2022). Currency Volatility impacts on the volume of international trade and foreign investments (Chong et al., 2002). Higher exchange rate viability adds uncertainties, which could discourage trade and investment (Frankel, 2003).Persistent currency volatility could even evolve into a crisis, adversely affecting many key policy variables, including interest rates and the return of investments, posing a downside risk on the exporting competitiveness, international investment portfolios, international reserves, debt payment, and economic stability and growth (Das & Roy, 2022).

Two measures of financial volatility in the financial domain are the historical volatility and the implied volatility. Historical volatility uses the past values of the exchange rates to calculate the standard deviation of the exchange rate while implied volatility is the market participants' estimation of the volatility reflected in the asset pricing by the Black Scholes option pricing model.

One strand of theories focuses on the *macroeconomic fundamentals in determining exchange volatility*. This argues that the foreign exchange rate fluctuates according to the demand and supply flow of the pair currencies such as output, money growth, inflation, and interest rate volatility (Flood & Rose,1999; Friedman, 1953; Frankel, 2003; Dick et al., 2015).

The other strands of theories argue that the currency volatility comes from *microstructure factors* (Flood & Taylor, 1996; MacDonald, 1999; Morana, 2009). These theories focus on the "order flow" instead of the macro fundamentals in the exchange rate markets. Order flow is the difference between buyer-initiated and seller-initiated orders in a securities market (Vitale, 2006). Zhang et al. (2013) examine order flow and exchange rate dynamics in China by market microstructure analysis.

Historically, emerging economies are prone to speculative attacks and crises

(Ötker & Pazarbaşioğlu, 1997). During the crisis, the emerging economies experience an unprecedented increase in capital outflow due to “flight to quality” behaviour and the shift of investors’ risk aversion (Gunay, 2021). Moreover, the devaluation of the currency of developing countries tends to spike the speculation. In the meanwhile, the commodity price change could have persistent and larger impacts on emerging economies (Phiri, 2022). The above mechanisms cause spillover effects from one market to another market, and from one country to another country, with emerging markets generally being the shock receptors.

2.2.2.1 Interest rate differentials and exchange rate

According to the Uncovered Interest Parity (UIP) theory, the interest differentials are, on average, equal to the ex-post exchange rate change. The change of interest differentials between two countries is one of the determinants of currency volatilities. When the interest rate differentials between the two countries change, the direction or the scale of capital flow changes accordingly.

However, the effectiveness of UIP in the current context has been criticised by many researchers. Flood and Rose (2002) argue that the UIP worked better in 1990s and for the crisis countries whose exchange rates and interest rates demonstrated more volatilities.

Fratzscher et al. (2012) confirm that FED monetary policy after 2007 contributed to the portfolio reallocation and risk repricing in global financial markets. The research found countries with more active monetary policies and high-quality institutions are less exposed to US unconventional monetary policy shocks.

Bowman et al. (2015) investigated the US conventional and unconventional monetary policy effect on the exchange rates of 17 emerging market economies by the vector autoregression model. The study found that the countries with

high interest rates, current account deficit, slower GDP growth, less flexible currency regimes, and more vulnerable banking systems are more affected by changes of the FED financial variables (Bowman et al., 2015).

Bruno and Shin (2015) argue that the leverage of the global banks and VIX index (stock market option based implied volatility, used by researcher as an indicator for market risk aversion) mediates how much contractionary monetary policy affects the exchange rate. In detail, the contractionary monetary policy decreases cross-border banking capital flows and declines in the leverage of international banking.

Hausman and Wongswan (2011) use two proxies for monetary policy surprises: the surprise change to the current target federal funds rate (target surprise) and the revision to the expected path of future monetary policy (path surprise). The research found that exchange rates and long-term interest rates respond mainly to the path surprise; and short-term interest rates respond to both surprises. More importantly, stock indexes and interest rates in countries with less flexible exchange regimes respond more to US monetary policy surprises. The research found the variation to be strongly related to each country's stock market capitalisation relative to its GDP.

Deng et al. (2022) analysed the spillover effect of the US monetary policy normalisation on the total output, inflation, exchange rate, and trade balance of BRICS countries, applying the panel Vector Autoregression approach by the monthly data between 2008 and 2018. The result demonstrates that the FED’s interest rate hike and balance sheet shrinking would lead to output decrease, inflation decline, exchange rate depreciation and trade balance deterioration in BRICS countries. The authors argue that the spillover effects would be long lasting and therefore they propose enhanced regulation, strengthened policy coordination and communication among BRICS countries to mitigate the risk.

Frankel (2007) argues that the South African Rand behaves like industrialised economies within a developed financial system, and the Rand's volatility is explained by interest rate, expected inflation rate and sovereign default risk.

According to Bekaert et al. (2013), the loose monetary policy reduces risk aversion and uncertainties. Therefore, Bekaert et al. (2013) employ high frequency changes in the futures rate around the Federal Open Market Committee (FOMC) announcement as the measure of monetary surprise.

2.2.2.2 Commodity price and exchange rate

Commodity price and exchange rate co-movement has been explored by many studies (Boubakri et al., 2019; Cashin et al., 2004; Dib, 2008). Amongst them, oil and gold, as the most important commodities, have been of great interest to researchers. The oil price-exchange rate transmission is believed to be through three channels: terms of trade (Amano & Van Norden, 1998); wealth effects (Golub,1983) and portfolio relocation (Krugman, 1983). For terms of trade, the oil price increase will deteriorate the oil importing country's current account and, in turn, lead to the depreciation of the currency. Backus and Crucini (2000) argue that the change in oil price could explain most variations of the term of trade. The oil price increase will also transfer the wealth from oil importing countries to the oil exporting countries, which will result in the depreciation of the importing countries through an imbalance of the current account and the portfolio relocation (Golub,1983).

The international portfolio allocation model by Krugman (1983) presents three models of the asymmetry of the impact of oil prices on the exchange rates. Assuming OPEC will progressively spend its surplus to import more goods from developing countries, Krugman argues the long run effect of an oil price increase on the dollar exchange rates will depend on the weight of oil in the US total imports compared to the US weight in OPEC's imports. In the short run,

the effect depends on the US weight in the global oil imports compared to the weight in the dollar denominated assets held by OPEC. Krugman argues that the oil price changes will affect all countries and as the effects on the exchange rates rise from the asymmetry between the two countries.

Fratzscher et al. (2014) found a bidirectional causality between the change of US dollar and oil prices. It was discovered that a 10% increase in oil price leads to a 0.28% depreciation of the dollar's effective exchange rate while, if the dollar weakens by 1%, oil prices rise by 0.73%.

Chen et al. (2016) investigated the impacts of oil price shocks on the bilateral exchange rates of the US dollar against currencies in OECD countries. They found that oil price shocks can explain about 10–20% of long-term variations in exchange rates. The explanatory ability of oil shocks to exchange rate variations becomes much greater after a global financial crisis. Baek (2021) examined the oil-exporting countries and concluded that the relationship between oil prices and exchange rates depends on the exchange rate regime.

Chen et al. (2022) investigated asymmetric volatility spillovers and dynamic correlations between crude oil price, exchange rate and gold price in BRICS countries. The results indicate that gold is the ultimate recipient of volatility spillovers between the three markets in Brazil and India and the nexus between China’s exchange rate market and crude oil market. Volatility spillovers between the three markets in Russia formed a bidirectional closed transmission path. South Africa had a weak link between its exchange rate and gold markets with the crude oil market. In the research, an asymmetric VAR-BEKK(DCC)-GARCH model was estimated using the daily data from August 2005 to March 2020.

Kin and Courage (2014) assert that the oil price has a significant impact on the South African nominal exchange rate, and that the increasing oil price leads to

the depreciation of the Rand. Fowowe (2014) confirms that a 10% increase in global oil price leads to 1.4% of the depreciation of the Rand by using GARCH autoregression conditional jump intensity model.

More recently, Salisu et al. (2022) also established that the oil price is a good predictor for the exchange rates of the BRICS currencies. Applying to both the oil importing countries, including China, India and South Africa, and the oil exporting countries, like Brazil and Russia, the authors' model suggests an asymmetrical effect of the oil price in which the increased effect on the exchange rates is more pronounced than the decrease.

On the other hand, the studies of the gold price to exchange rates are on both exporting countries, such as South Africa and Australia, and importing countries, such as India. Frankel (2007) suggests that the index of mineral prices is not the only way to determine the South African Rand's real value. Arezki et al. (2011) examined the gold price and the Rand exchange rate after the capital account liberalisation period and found that the gold price volatility explained the excessive volatility of the Rand exchange rate and the disproportional speculative inflow to South Africa. Similarly, Haque et al. (2015) confirm that the bi-directional causality exists between the gold prices and the Australian exchange rates, and a 1% increase in the nominal gold price leads to an appreciation of the AUD/USD nominal exchange rate by 0.5%. Jain and Biswal (2016) observed that a fall in gold prices and crude oil prices caused a fall in the value of the Indian Rupee and the Indian stock market index. Shiva and Sethi (2015) also confirm the presence of unidirectional causality that runs from the gold prices to the Rupee's exchange rate using the Granger causality test.

2.2.2.3 Geopolitical risks, economic policy uncertainty and exchange rate

Geopolitical risks are the risks concerning wars, terrorism, and tensions among states (Caldara & Iacoviello, 2022). Geopolitical risks increase the cost of

investing, and lead to lower local economic growth. Geopolitical unrest affects investors' expectations (Gaibulloev & Sandler, 2008), which have economic implications and cause exchange rate volatility in economies (Tiwari et al., 2013). Some recent studies relate the asset price movements with the GPR (Antonakakis et al., 2017; Cunado et al., 2020; Demirer et al., 2018; Dutta & Dutta, 2022; Omar et al., 2017; Plakandaras et al., 2019). Aslam and Kang (2015) argue that the relationship between exchange rates and geopolitical unrest is time-dependent and case-driven, influencing the dynamics of financial markets. Likewise, Arin et al. (2008) also found that the impact of geopolitical events on the financial markets varies from market to market, with a larger negative impact on emerging markets.

Hui (2022) uncovers geopolitical risk is a significant long-run driver for currency behaviours in Southeast Asian countries, and argues that a higher geopolitical risk leads to a depreciation of domestic currency. Salisu et al. (2022) examined the impact of geopolitical risks on the volatility of the BRICS countries' exchange rates, and found that their exchange rates are more vulnerable to the recent data (1985–2020) than the historical data (1899–2020), and that the exchange rates are more vulnerable to the global data than the domestic data.

Importantly, the mechanism between geopolitical risk and oil price is complex. Some scholars believe oil has become a cause of geopolitical uncertainty that makes its prices more volatile and vice versa (Su et al., 2020). A hike in oil prices affects production, consumption, and investment, resulting in decreased trade balance (Apergis et al., 2015). Therefore, it can be regarded as a major source of geopolitical unrest in recent times (Abdel-Latif & El-Gamal 2019, cited by Duan et al., 2021). Developed economies use the monetary policy to absorb oil price shocks and manage exchange rates (Qiang et al. 2019, cited by Duan et al., 2021).

On the other hand, the literature regarding the impact of EPU on exchange

volatility is less explored. Bloom (2014) argues that macro uncertainty rises sharply in recessions and falls in booms, explained by the leverage effect in the stock market, bigger size of surprise and the risk aversion changes during recessions. In addition, the policy generally stays the same when the economy is going well, but the politicians tend to experiment more during recessions, resulting in higher political uncertainties that vary across countries (Pastor & Veronesi, 2012). Research finds such uncertainties vary across countries. The research amongst 60 countries by Bloom (2014) indicates that countries with low incomes (less than $10,000 per capita) have a 50% higher volatility of growth rates, a 12% higher stock-market volatility, and a 35% higher bond-market volatility. Thus, overall developing countries experience one-third higher macro uncertainty. López and Bush (2019) show that greater political and financial uncertainty leads to higher exchange rate volatility in Mexico. The researchers reveal that measures of international uncertainty are found to dominate domestic uncertainty measures, although the domestic uncertainty has also an important effect on the exchange rate volatility. The authors also argue there is an amplifying effect of domestic economic uncertainty on exchange rate volatility, especially during periods of recession. Empirically, Demir et al. (2018) found that Bitcoin returns are negatively associated with the Economic Political Uncertainty index, but the effect is positive and significant at both lower and higher quantiles. Using data for 23 countries in the period 1996 to 2016, Phan et al. (2021) show that the impact of economic policy uncertainty on financial stability is negative, and the impact is stronger for countries with higher competition, lower regulatory capital, and smaller financial systems.

2.2.2.4 Foreign exchange regimes and exchange rate

The main foreign exchange regimes are firmly fixed, floating, and intermediate (Frankel, 2003). Researchers (Angkinand et al., 2009; Eichengreen,1998; Obstfeld & Rogoff, 1995) argue that efforts to operate adjustably pegged

exchange rate regimes have been a major contributor to “the unstable middle” hypothesis (or corner hypothesis). Some have argued that this unstable middle is so broad that only the two corners of hard fixes or floating rates will be stable in a world of high capital mobility – the two corners or bipolar hypothesis. The literature on advantages of the fixed foreign exchange regime is focused on its nominal anchor for monetary policy. When a currency is pegged to a hard and disciplined currency or a currency basket, the inflation of the country can be kept at a low level regardless of the GDP output (Frankel, 2003). The other advantages include preventing competitive appreciation/depreciation and precluding speculative bubbles in the market (Frankel, 2003).

For the floating regime, the flexibility of the exchange rates allows for an independent monetary policy, so the government can respond to recession by monetary expansion and inflation. It also allows automatic adjustment to trade shocks. The central bank, under floating regime, retains the function of lenders of last of resort and seigniorage.

Frankel (2003) asserts that both regimes could experience overvaluation, extreme volatility, and crashes. If a country is subject to many external disturbances, there is more possibility for it to adopt floating regimes.

Ha et al. (2020) confirms that pass-through measures of foreign exchange rate to consumer prices tend to be lower in countries that combine flexible exchange rate regimes and credible inflation targets and where central bank independence can greatly facilitate the task of stabilising inflation by using the exchange rate as a buffer against external shocks.

Among the five BRICS countries, China adopted the fixed exchange rate to US dollar during 1995 and 2005, and it has adopted the managed floating regime since 2005 (Wen & Wang, 2020). Russia and India started using freely determined exchange rates from 2014 and 1993 respectively. Brazil and South

Africa have used the floating exchange rate since 1999 and 2000 respectively. According to Wen and Wang (2020), China is taking a crawl like exchange regime, India, Brazil and South Africa are taking the floating exchange regime, while Russia is taking the freely floating exchange regime.

2.2.3 Volatility spillover and connectedness of the BRICS currencies

According to Aloui et al. (2011), accelerating international financial integration and liberalization of capital markets have led to increased capital flows, and thus increased co-movements in various financial markets and increased volatility spillovers. There is growing interest in volatility spillover and connectedness of currency markets. Black and McMillan (2000) , using data from 1974 to 1998, reveal the volatility spillovers across European currencies including French Franc, Italian lira, German mark, and British pound. McMillan (2001) found a high correlation between the volatility innovations in German and French foreign exchange rate and suggests that they follow a common trend and the volatilities are cointegrated.

Nyopa and Khumalo (2022), using the data from 1997 to 2018, found evidence of interdependencies between BRICS foreign exchange markets, except for China whose market is isolated with other BRICS countries. The study also found Brazil is the largest contributor of volatility spillovers to other BRICS markets, and South African Rand is the most integrated within BRICS. In detail, the Rand, RMB and Rupee are the volatility recipients, while Rupee and Real are the volatility transmitter to other BRICS exchange markets.

Das and Roy (2022) also reveal the currency connectedness of BRICS countries in terms of the co-movement and volatility spillover. Employing the MGARCH-DCC model and applied VAR based spillover index, the authors found that, along with the BRICS currency volatility, the Russian Ruble and the RMB are explosive, and a co-movement and volatility spillover exists among

the foreign exchange markets across different countries. The currency markets of the developed countries were found to transmit volatility to the emerging economies. The degree of spillover varies across countries, with Brazil and Russia passing on volatility to the developed countries whereas India, China, and South Africa receive volatility from their developed counterparts.

Saji (2019) found divergent real exchange market behaviours of the member countries before the formation of BRICS, but the convergences in central bank's direct intervention behaviours is evident, especially for India, China and South Africa after 2010. The author argues that the inclusion of the stronger policy interaction in the region, especially in monetary management, improves the chance of a strong currency union among BRICS members. In the research, Saji (2019) employed the Markov switching approach to model the real exchange rate of the BRICS countries.

Based on ADCC results and Diebold-Yilmaz volatility index, VAR framework enhanced by Greenwood-Nimmo block aggregation technique, Mittal et al. (2019) investigate the dynamic currency linkages between the countries in the emerging market, and discover that Brazil is a net transmitter in currency market while Russia, India and South Africa are net receivers of information.

2.2.4 Optimal Currency Area

A currency area is the monetary union of one country or one region, with other countries. The framework for the optimal currency area (OCA) by Mundell (1961) and McKinnon (1963) suggests four preconditions of an optimal currency area: the openness and integration of the economies; the factor market integration; the similarity of the economy structure and symmetry to the real shocks; and the integration of the financial market.

Sato et al. (2009) employ the multivariant Johansen cointegration method to check the long run co-movement of the outputs among the East Asian countries,

Japan and the US. The authors argue that China is not suggested as a member country of a monetary union with any of the grouped economies, according to the data 1978–2006.

Lee and Koh (2012) employed a structural Vector Autoregression (VAR) approach to access the nature of the macroeconomic disturbance among East Asian countries in comparison to the Euro zone countries. The authors found the East Asian countries were less symmetric to shocks but the speed of adjustment to shocks is faster. The authors argue that the difference can be explained by the higher factor mobility (higher labour mobility and capacity mobility). They also found that the increased symmetry of the shocks after the Asian financial crisis indicating the regional policy coordination efforts after the crisis. The sample period for East Asian countries was 1970–1996 and 1970–2008. The sample period for the European countries was 1960–1998, before the European Monetary Union (EMU) was established.

Mishra and Sharma (2010) tested the Purchasing Power Parity (PPP) and Generalized PPP hypothesis in a group of eight Asian countries to investigate the symmetry in macroeconomic disturbances and the co-movement of bilateral real exchange rates of the east Asian countries. It was backed by Mundell's (1961) argument that real output levels and probably expenditure patterns will share a common trend in an OCA. The GPPP theory agreed that the real exchange rate of a group of countries may be individually non-stationary but, if the fundamental macroeconomic factors that drive the exchange rate are sufficiently integrated across countries, a linear combination of these non-stationary real exchange rate will be stationary, and they will share common trends in the long run. The authors tested the mean reversion property of the USD or Yen based exchange rate of eight Asian countries for pre- and post-crisis periods. Then, the Johansen cointegration method was applied confirming that the bilateral real exchange rate shares a stochastic trend. The

presence of the asymmetries in the process indicated that a higher level of economic integration is required to strengthen the case of a currency union.

Bayoumi and Eichengreen (1994) applied the aggregate demand/aggregate supply model to test the shocks, isolating the permanent and transitory effects of the macroeconomic shocks. The research found that a positive demand shock will increase both price and output in the short run but only price in the long run, while a positive supply shock will increase output and decrease price in the short and long run. In another words, while supply shocks have long run permanent effects on the level of output, demand shocks only have temporary effects (Lee & Koh, 2012). The authors argue that the faster the adjustment to the disturbance, the smaller the cost of renouncing the monetary sovereignty. The authors used standard deviation to measure the sizes of the aggregate supply shocks and aggregate demand shocks, and they took the value of the impulse response function after five years to measure the speed of adjustment.

Rafiq (2011) investigated the cost of a unified currency in Gulf Cooperation Council (GCC) countries on asymmetric shocks. By using the VAR model, Rafiq (2011) focused on the idiosyncrasies and regularities between the GCC output fluctuations and examined two issues: 1) How frequent and severe asymmetric shocks are now; and 2) How frequent and severe would shocks be after the countries move to adopt a common currency. The sample period was from 1980 to 2005. The result confirmed the business cycle linkage in Gulf countries, while the strengths vary over time, depending on the nature, magnitude and origin of disturbances that affect each economy. The result shows strong evidence that oil prices are a statistically significant factor behind the shared component driving GCC output cycles, which is not surprising given the constituent countries' economic structures. The author argues that if the suitability of the a group or regions for the formation of a currency union is endogenous, then adopting a common currency will likely change the relative importance of

common and idiosyncratic shocks and alter the suitability of a region for a currency union.

Hochreiter et al. (2002) inferred from the EMU experience that, for a monetary union to be sustainable requires fiscal policy rules, labour market flexibility and sound financial markets. The authors investigated the cost and benefits of giving up a national currency for the European, Latin American and Caribbean countries. Among them, the worldwide shift of the monetary and exchange rate regimes were examined, the trade benefit and exchange rate volatility elimination, hence lower interest rates, were evident, and cost, such as policy instruments and asymmetric shocks, loss of seigniorage and political tension were also examined. The conclusion was that the Latin American and Caribbean region is some distance away from satisfying the necessary conditions for a monetary union.

2.2.5 Internationalization of RMB

Some researchers have predicted the RMB will rise to become the dominant reserve currency, eroding dollar's dominance (Subramanian, 2011; Prasad & Ye, 2012). The inclusion of the RMB in the special drawing rights (SDR) basket by the International Monetary Fund (IMF) in 2016 was an important milestone for the RMB's Internationalization and paves a way for greater diversification of the reserve assets (L'hôtellerie-Fallois et al., 2016).

However, in 2021, the official central banks foreign reserves in RMB were only 2,8%, and global cross- border payments in RMB were only 2% (Perez-Saiz & Zhang, 2023). Tavlas (1990) argues that an attractive international currency must be associated with financial markets that are open, free of control, broad, with a large assortment of financial instruments, and with deep, well-developed secondary markets. Likewise, Liu and Papa (2022) agree that the financial market for Euro dominated assets lacks the depth and size of the dollar

dominated markets, constraining the Euro's capacity to challenge the dollar hegemony in global financial markets.

Looking at the aspects of the Chinese financial system, Dobson and Masson (2009) maintain that, even though China experiences low inflation and high GDP growth, and export shares are large and growing fast, but the strict capital control, the underdeveloped financial system and the exchange rate regime need a reform to improve the convertibility and capital market liquidity, before the Chinese RMB could emerge as an important regional or world currency. Frankel (2012) indicates that RMB's internationalisation will take longer due to a lack of financial development and mobility. Recently, Otero-Iglesias & González-Agote (2024) also agree the incomplete openness of capital account, lack of flexibility in RMB exchange rate and geopolitical tensions have hinder the internationalisation of RMB.

2.3 Research propositions

Based on the above knowledge, the study presents three propositions:

Proposition One: Interest rate differentials, commodity price, geopolitical risk, and economic policy uncertainty affect BRICS' currencies volatilities.

Proposition Two: The impacts of the determinants of the BRICS nations' currency volatilities are symmetrical.

Proposition Three: long term volatilities connectedness exists among the BRICS countries' currency markets.

2.4 Conclusion

This chapter reviewed the literature on currency volatility and the possible factors which affect currency movement: oil price, gold price, interest rates, and geopolitical risks. The improved cointegration is a consequence of trade density

and BRICS corporation. It also re-examined the relevance of the theory of optimal currency area, assessed the methodologies on testing co-movements, casualty, and volatility extraction, and examined the proxies that were adopted by the researchers.

CHAPTER 3: METHODOLOGY

3.1 Research Design

A research design is a plan before data collection to achieve a research objective in a valid way (Asenahabi, 2019). The plan involves data collection and analysis activities to ensure that the research agenda is addressed to answer the research questions (Bickman et al., 2009).

A research method is categorised as either qualitative, quantitative or a combination of both. Quantitative research focuses on objectivity and is especially appropriate when there is the possibility of collecting quantifiable measures of variables and inferences from samples of a population (Queirós et al., 2017). To achieve accurate and reliable measurements that allow statistical analysis (Queirós et al., 2017), a quantitative method was employed in this research. The purpose of this study was to empirically test theories, verify previous academical research with new data and to make the research results generally applicable instead of case specific. Thus, the quantitative method was appropriate for this research.

Quantitative research adopts structured procedures and formal instruments for data collection. The data are collected objectively and systematically (Queirós et al., 2017). In this study, time series analysis was conducted by the secondary data collected from reliable databases, such as Bloomberg, the World Bank, the IMF, and the central banks' official sites. The sources ensured the creditability and verifiability of the data.

The analysis of numerical data in a quantitative study is performed through statistical procedures, often using software such as SPSS, R or Stata (Queirós et al., 2017). In this research, EViews 13 software was used for data analysis.

The time dimensions for this research were longitudinal and cross-sectional. The scope of the research was statistical.

3.2 Sample and population

In quantitative research, the samples are generally large and thus are considered representative of the population. The results are taken as if they constituted a general and sufficiently comprehensive view of the entire population (Martin & Bridgmon, 2012). A non-probabilistic sampling method, or non-randomness sampling, does not involve taking representativeness into consideration as the desirable purpose for the sample description. The sampling method usually allows the researcher to decide which of the investigated population components will be selected (Rozalia, 2007). In this study, non-probabilistic sampling was adopted to purposively include the data from a continuous period, after BRICS formation in 2010, pre- and post-COVID-19 pandemic, and the most recent data until late 2023.

The sample observations were the monthly exchange rates to the dollar for five BRICS countries' currencies (Brazil, Russia, India, China, and South Africa), during the period of September 2011 to September 2023. The sample size is 145. The large samples ensure the representativeness of the sample and could effectively mitigate bias. Monthly data were preferred, rather than the high frequency daily data since the research's interest was on the trends and dynamics of currency volatility.

The research included the most recent data up to September 2023 to incorporate the recent dynamics in interest rate differentials, commodity prices, and events reflecting high geopolitical risks and economic policy uncertainties. The underlying rationales were: 1) Obtaining the data from the recent period with the rise of high-risk factors could well show the effect of market shocks on the currency volatilities; 2) The recent shocks, e.g. COVID-19, the Russia-

Ukraine war and the series of FED interest rate hikes, were very relevant to the research; and 3) The recent data explained the evolution trend in currency volatilities, which is more meaningful for investors, managers and policymakers under the current situation. The choice of period was justified by data availability.

3.3 Data and data sources

The data type was secondary time series data. In the research, monthly foreign exchange rates denoted in USD for the five BRICS countries were collected. The exchange rate to unity is normalized and 100 times the natural logarithm of the exchange rate is applied for the analysis. Then the returns by the difference of log value are calculated, followed by the currency exchange rate volatilities that were calculated by the GARCH (1,1) model.

The other data collected included the monthly West Texas Intermediate Crude Oil index (WTI) denoted in USD, the monthly gold spot price denoted in USD, the monthly Geopolitical Risk Index (GPR) of the five countries and the USA, and the monthly Economic Policy Uncertainty (EPU) index for four countries and the USA, except for the South African EPU index that was not available.

Additionally, FED fund rates and primary central bank interest rates for the five BRICS countries are collected, for example, Benchmark Primary Loan Rate (before Oct 2015) and LPR (after Oct 2015) for the People's Bank of China, the REPO rate for the South African Reserve Bank, etc. Inflation rates of the five BRICS nations and the USA were also collected for the purpose of deflating the rates and calculating the real interest rate differentials.

Table 1.1: Description of the variables

Variables	Description	Units	Source
Independent variables			
Variance of Currency	Variance of the return of curency price per USD		Nominal exchange rate from Bloomberg and Real exchange rate from BIS website
Dependent Variables			
Interest Differential with USA	Difference of the real interest rates of the nation to US	base points	Policy interest rates and inflation rates from Bloomberg or central banks' websites
Oil	Close price for spot WTI, in logarithmic term	USD per barrel	Bloomberg
Gold	Close price for spot gold, in logarithmic term	USD per ounce	Bloomberg
GPR:	Index based on frequency of newspaper counts	index	www.matteoiacoviello.com
EPU:	Index based on frequency of newspaper counts	index	https://www.policyuncertainty.com/
Economy Openness:	(Import+Export)/GDP	ratio	Real GDP data from World Bank GEM database; import and export data from IMF
Foreign Reserves:	Total Reserves in USD, in logarithmic term	Billion USD	Bloomberg
Stock Market Index:	The main Stock Market Index price, in logarithmic term	index	Bloomberg
FX Trading Volume :	Foreign Exchange Trading Volume, in logarithmic term	Billion USD	Thomson Reuters Datastream Database

The GPR index is the index proposed by Iacoviello and Caldara (2020) and used as a proxy for geopolitical uncertainty used by several researchers (Al Mamun et al., 2020; Salisu et al., 2022; Su et al., 2020). The occurrence of text regarding geopolitical tensions from newspapers was automated to measure the GPR in the historical and current periods.

The EPU index is the index measure policy-related economic uncertainty constructed by Baker, Bloom and Davis (2016). The index is based mainly on newspaper coverage of policy-related economic uncertainty.

The study controlled the variables according to previous empirical literature. The control variables included: economy openness (Hau, 2002; Mpofu, 2016); foreign reserves (Mpofu, 2016; Ötker & Pazarbaşioğlu, 1997); the stock market index (Erdoğan, Gedikli & Çevik, 2020; Mishra et al., 2007); and trading volumes in foreign exchange markets (Mougoué & Aggarwal, 2011). The variables were considered as potential determinants of currency volatilities.

Therefore, the import and export volumes, GDP based on PPP, and the foreign reserve of the five nations were collected. The quarterly GDP collected was interpolated to monthly data by the Cubic Spline method. The economy openness was calculated by $\frac{Import+Export}{GDP}$ according to the literature.

The data on currencies, commodities and economic fundamentals were sourced from Bloomberg, Reuters DataStream, IMF, OECD, World Bank, BIS Bank and central banks' official websites, as shown in **Table 1.1**.

In the study, logarithm terms for the WTI price, gold price, GPR, EPU, foreign reserves, stock market index price, and trading volumes are used. The logarithm term could effectively correct for the potential heteroscedasticity for macroeconomic data (Chen et al., 2018). For the real interest rate differentials and economy openness ratio, I used base points as a unit, which is 100 times

the % term.

3.4 Empirical models and research analysis

3.4.1 GARCH (1,1) Model

This research used the GARCH (1,1) model to specify the currency exchange volatility. Studies (Bollerslev, 1987; Diebold, 1989 cited by Chong et al., 2002; Friedman & Vandesteel, 1982) show that the foreign currency exchange return is non-linear, temporal dependent and the distributions of the return are leptokurtic. These studies found that the volatilities of the exchange rate are "clustered" together over time and the distribution is bell shaped, symmetric, and fat tailed (Chong et al., 2002). These features of data are best captured using the Autoregressive Conditional Heteroskedasticity (ARCH) model and Generalized ARCH (GARCH) model (Alam & Rahman, 2012; Kamal et al., 2012; Kearney & Patton, 2000 cited by Chong et al., 2002). These nonlinear models do not assume the variance is constant. Under the ARCH model, the autocorrelation in volatility is modelled by allowing the conditional variance of the error term to depend on the immediately previous values of the squared error. The GARCH model allows the conditional variance to be dependent on previous own lags (Brooks, 2019).

Specifically, Hansen and Lunde (2005) show that the GARCH (1,1) model is good for modelling currency exchange volatility and found no evidence that more complicated models outperform the GARCH (1,1) in modelling exchange volatility. The comparison was made by 330 GARCH-type models in terms of their superior predictive abilities and reality checks for data scooping.

Abdalla (2012) uses the GARCH (1,1) and EGARCH models to show the exchange rate volatility in a panel of 19 Arab countries and reveals that the GARCH (1,1) model is adequate for modelling currency volatilities.

The GARCH model, proposed by Bollerslev in 1986, generalises Engle's Autoregressive Conditional Heteroscedasticity (ARCH) model. The mean equation for the GARCH (1,1) model is as follows:

$$r_t = \mu + \varepsilon_t \quad (3)$$

Where r_t is the return of the asset at time t, μ is the average returns, ε_t is the residual.

The variance equation for the GARCH (1,1) model is as follows:

$$\sigma_t^2 = \gamma V_L + \alpha u_{t-1}^2 + \beta \sigma_{t-1}^2 \quad (4)$$

Where σ_t^2 represents today's variance, σ_{t-1}^2 is the variance of the previous day, u_{t-1}^2 denotes the square of the previous day's return, and V_L is the long run variance rate. The constraints $\alpha \geq 0$ and $\beta \geq 0$ are needed to ensure σ_t^2 is positive (Abdalla, 2012). It is also required that $\alpha + \beta$ is less than 1.

3.4.2 ARDL Model

The analysis started with unit root tests. After confirming that the data were stationary, the study applied an Autoregressive Distributed Lag Cointegration model (ARDL) with GARCH specifications to estimate the relationship between currency volatility and the determinants.

The ARDL method was proposed by Pesaran et al. (2001). The advantages of the ARDL model are that it allows the study of volatility in the long and short term, and eliminates the endogeneity and serial correlation. Therefore, the study observed the long-term dynamic relations among the variables. The ARDL model also allowed the variables to have different lag structures (Nouir & Hamida, 2023). The ARDL methodology was applied by Nouir and Hamida (2023) in testing the relationship between bitcoin volatility and predictive

variables. The approach was applied by Mokoena et al. (2008) to examine the long run cointegration of order flow, fundamentals and non-fundamentals, with the Rand/Dollar Real exchange rate.

The ARDL model estimation in this study is expressed as follows:

$$\Delta Currency\ Vol_t = c + \gamma ECT_{t-1} + \beta_1\ Interest\ Dif_{t-1} + \beta_2 WTI_{t-1} + \beta_3 Gold_{t-1} + \beta_4 GPR_{t-1} + \beta_5 GPR\_US_{t-1} + \beta_6 EPU_{t-1} + \beta_7 EPU\_US_{t-1} + \beta_8 Openness_{t-1} + \beta_9 Reserve_{t-1} + \beta_{10} Volume_{t-1} + \beta_{11} StockIndex_{t-1} + \sum_{i=1}^{q_1} \alpha_{1i}\ \Delta Currency\ Vol_{t-i} + \sum_{i=1}^{q_2} \alpha_{2i}\ \Delta Interest\ Dif_{t-i} + \sum_{i=1}^{q_3} \alpha_{3i}\ WTI_{t-i} + \sum_{i=1}^{q_4} \alpha_{4i}\ \Delta Gold_{t-i} + \sum_{i=1}^{q_5} \alpha_{5i}\ \Delta GPR_{t-i} + \sum_{i=1}^{q_6} \alpha_{6i}\ \Delta GPR\_US_{t-i} + \sum_{i=1}^{q_7} \alpha_{7i}\ \Delta EPU_{t-i} + \sum_{i=1}^{q_8} \alpha_{8i}\ \Delta EPU\_US_{t-i} + \sum_{i=1}^{q_9} \alpha_{9i}\ \Delta Openness_{t-i} + \sum_{i=1}^{q_{10}} \alpha_{10i}\ \Delta Reserve_{t-i} + \sum_{i=1}^{q_{11}} \alpha_{11i}\ \Delta Volume_{t-i} + \sum_{i=1}^{q_{12}} \alpha_{12i}\ \Delta StockIndex_{t-i} + \varepsilon_t \quad (5)$$

Where Currency Vol is the currency volatility, Interest Differential is the real interest rate differential between the country and the USA, WTI is the logarithm term of the oil price, Gold is the logarithm term of the gold price, GPR represents the Geopolitical Risk Index of the country in logarithm terms, GPR_US is the geopolitical risk index of the US, EPU represents the economic policy uncertainty of the nation in logarithm terms, EPU_USA is the economic policy uncertainty of the USA , and volume is the foreign exchange transaction volume of the currency in logarithms terms. q_j denotes the optimal lag determined by AIC minimum criteria. c is the intercept, ECT is the error correction term, ε_t is the error. β is the coefficient of a long term relationship and α is the coefficient of the short term relationship.

3.4.3 Quantile Regression (QR) Model

The QR (at 10% and 90% quantiles) was adopted in the research to test the relationship between volatility and variables under extreme conditions due to

the consideration that the tail behaviour of the volatility was of great interest to investors and policy makers. QR is a method used to estimate the median instead of the mean of the observations, by minimising the sum of absolute residuals (Koenker & Bassett, 1978).

QR is widely used in financial research. Saastamoinen (2008) used the method to investigate the Danish stock market herding behaviour. Badshah (2013) also adopted it to analyse the asymmetric return and volatility relations in the US stock market. Chen et al. (2018) argues that the QR model has the distinctive advantage of detecting the variation in the effect of EPU on the distribution of exchange rate volatility. Therefore, QR was appropriate for this research since it allowed me to investigate the relationship between volatility and its explanatory variables at extreme levels.

Additionally, the consideration of quantile regression is its ability to address potential heteroskedasticity. There are a few studies using QR to address the currency volatility's heteroskedasticity problem (Huang et al., 2011; Nouir & Hamida, 2023; Viola et al., 2019).

The QR model by Koenker and Basset (1978) is as follows:

$$y_i = x_i'\beta_\theta + u_{\theta i} \quad (6)$$

Where y_i is the dependent variable, β_θ is an unknown k x 1 vector of estimated regression parameters for values of θ (from 0 to 1), x_i is a k x 1 vector of independent variables, and $u_{\theta i}$ is the unknown error term.

According to Sevillano and Jareño (2018), the conditional quantile of y_i given x_i is as follows:

$$Q_\theta(y_i / x_i) = x_i'\beta_\theta \quad (7)$$

By minimizing function to β, we estimate the vector β_θ:

$$\{\Sigma_{t:yt>x_i'}\ \theta\ |\ y_t\ -\ x_t'\ \beta\ |\ +\ \Sigma_{t:yt>x_i'}\ (1-\theta)\ \|\ y_t - x_t'\beta\ \|\ \}$$

(8)

According to Sevillano and Jareño (2018), the QR applies the generalized method of moments or linear programming with the simplex algorithm. Thus, we minimize the sum of the weighted absolute error terms so that the positive and negative residuals are differently weighted according to the chosen quantile.

3.5 Ethical considerations

The ethical considerations in research generally include formal permissions, informed consent, unintended consequences, conflict of interests, confidentiality, and anonymity, where applicable. Even though secondary public data were employed in the research, there were ethical considerations during the data handling, collection, storage, and analysis phases. Concerns about the secondary use of data mostly revolved around potential harm to individual subjects and issues of return for consent. Sources of the original data were acknowledged and kept safe from unauthorised access, accidental loss or destruction (Tripathy, 2013).

3.6 Conclusion

Chapter 3 introduced the research design and presented the sample period and data collection process. It also discussed the GARCH model, ARDL model and QR model for the volatility specification, long run and short run relationship estimation and tail observations in this research.

CHAPTER 4: FINDINGS AND DISCUSSIONS

This chapter introduces the research process and discusses the findings. The study generated the variance series, which is the proxy of the currency volatility; investigated the descriptive statistics of the variables; analysed their distributions; presented the stationarity tests for the variables, since stationarity at I(0) or I(1) is the precondition of ARDL model estimation; investigated the ARDL models for the five countries with both long run co-integration and short run relations; and conducted Quantile Regression to eliminate the heteroskedasticity problem and to investigate the tail behaviour of the currency volatility. Finally, the cointegration of five currencies' volatility was tested. The findings are discussed based on the ARDL model and Quantile Regression.

4.1 Dependent variable: Currency volatility

The research started by generating the volatility series. The GARCH (1,1) model was utilised to get the currency volatility specifications. First, The ARIMA forecasting was conducted, and then the Least Squared estimations were conducted according to the ARIMA optimal lag suggestions. Using minimum Akaike information criteria, the optimal lag was selected. The residual ARCH effects were tested and confirmed. Secondly, GARCH (1,1) models were estimated. To ensure a GARCH model estimation is effective, the coefficients of ARCH effect and GARCH effect should both satisfy the non-negative constraints. Additionally, to ensure the model is stable and not explosive, the coefficients of the ARCH term and the GARCH term should add up to less than 1. The estimation process used the Variance Targeting method which is believed to be robust (Hull, 2018), except for the Russia Series. Variance Targeting took the historical long run variance as V_L in **Equation (4)**, so that there were only two coefficients to be estimated, given that the long-term average variance V_L can be expressed as ω / (1 - α - β).

The GARCH (1,1) models' estimation results are presented in **Table 4.1**. Moreover, **Figure 4.1** and **Figure 4.2** show the graphs of the currency return and currency volatility series.

Table 4.1: GARCH (1,1) specifications for currency variance

	Brazil	**Russia**	**India**	**China**	**South Africa**
Method	Variance Targeting	None	Variance Targeting	Variance Targeting	Variance Targeting
Constant	5,5141	3,7378	0,1496	0,0220	0,1241
ARCH term	0,2560***	0,3458*	0,1162***	0,0897**	0,07923***
GARCH term	0,4700***	0,6249***	0,8467***	0,8959***	0,9128***
Log likelihood	-416,903	-426,573	-283,052	-218,685	-222,836

Note: ***, ** represent significance at 1% and 5% levels. ARCH term is the news about volatility from the previous period, measured as lag of the squared residuals form the mean equation ε_{t-1}^2, and GARCH term is the last period variance σ_{t-1}^2

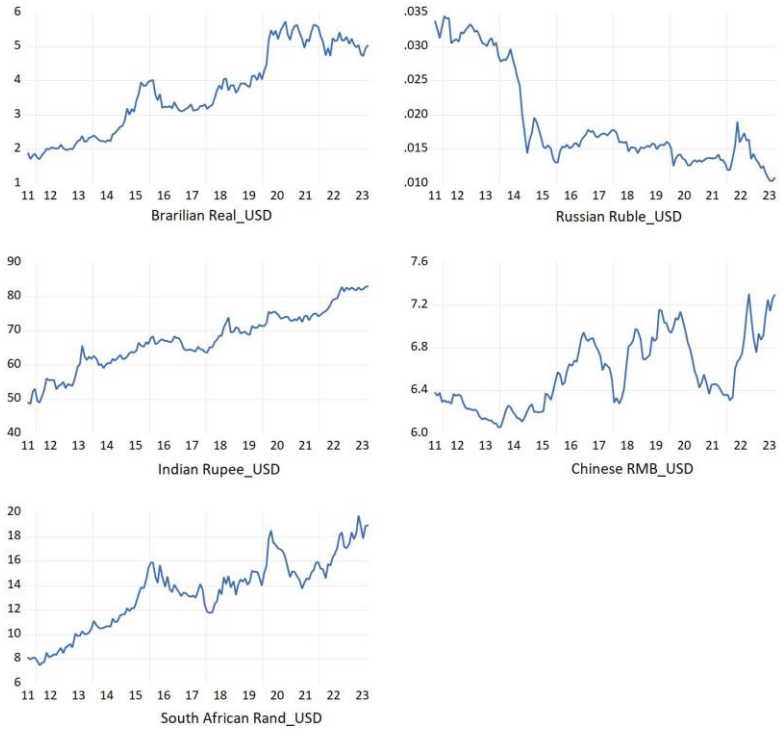

Figure 4.1: Nominal exchange rates for the five BRICS currencies

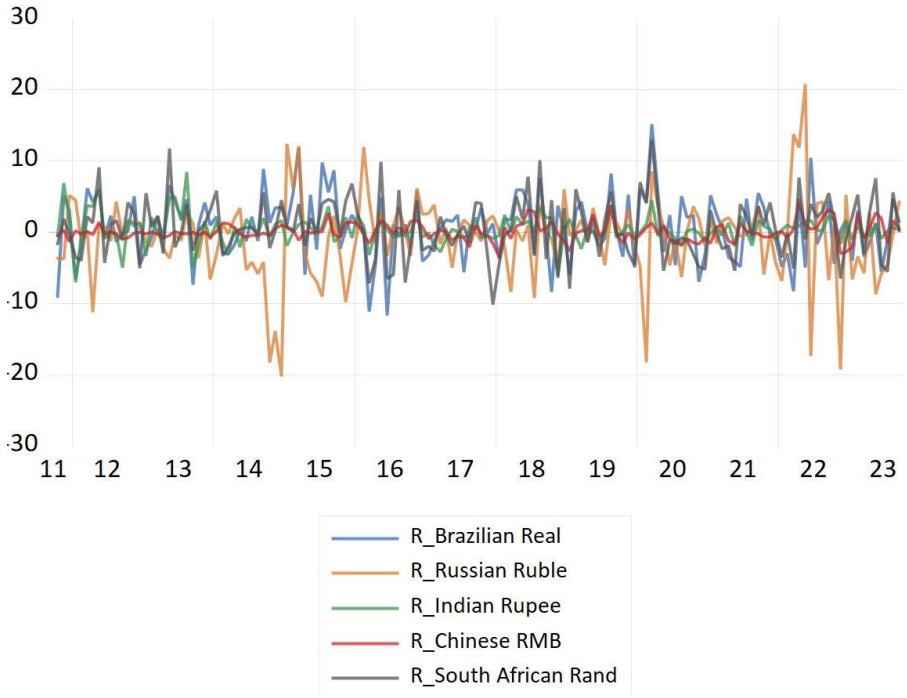

Figure 4.2: Returns of the five BRICS currencies

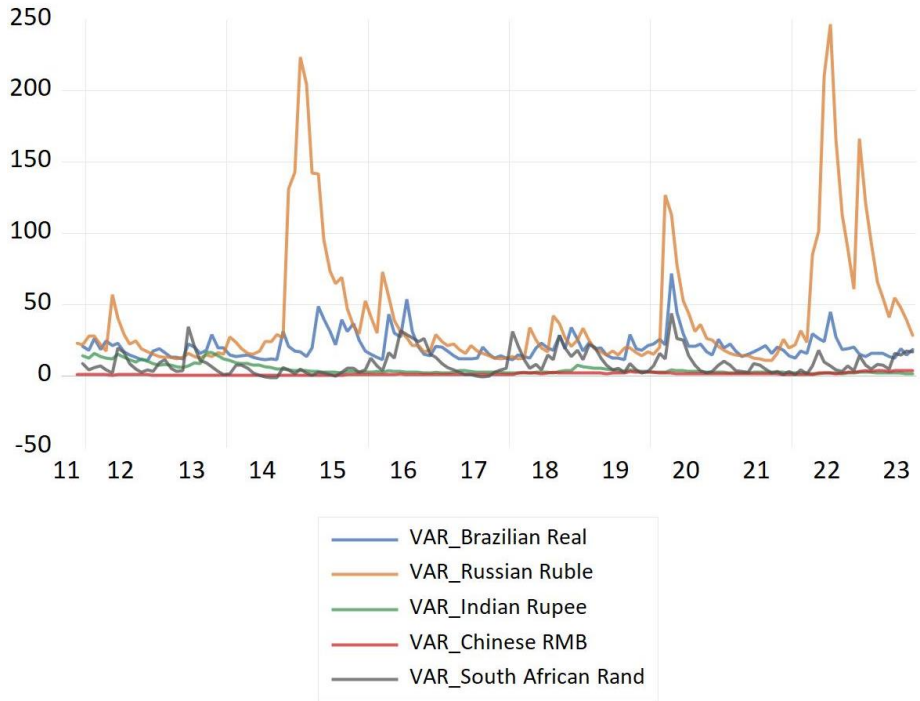

Figure 4.3: Volatility comparison of the five currencies specified by the GARCH (1,1) Model

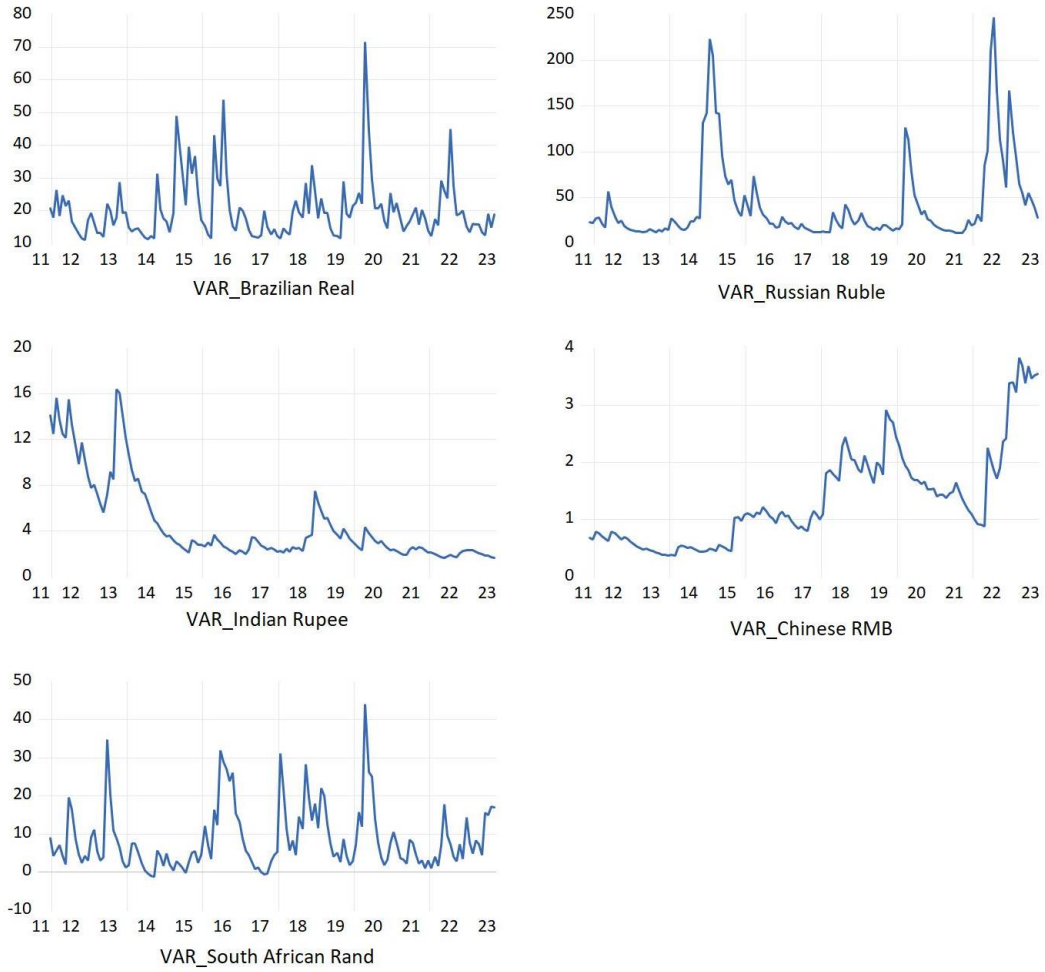

Figure 4.4: Variance of the five BRICS currencies specified by GARCH (1,1) models

4.2 Descriptive statistics

This section examines the descriptive statistics of all the variables to view series' mean, median, standard deviation, skewness, kurtosis, and normality.

Currency volatilities: Chinese currency has the least volatility, and the Russian Ruble has the highest volatility as shown in **Table 4.2**. The high volatility of the RMB concentrated in years 2022 and 2023 is shown in **Figure 4.4.** The Ruble's volatility concentrated in the period after 2022 in line with the gas price surge and fall during the European Energy Crisis in 2022 and the outbreak of the Russia-Ukraine war. The Indian currency shows a trend of less

volatility, even during and post the COVID-19 pandemic. All the volatility series were skewed to the right, implying the existence of high volatilities. All the series show kurtosis and non-normality. The results are in accordance with the study of Blau (2017) who claims that currency volatility series generally show fat tails or excess kurtosis.

Table 4.2: Descriptive statistics for the variables

		Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Prob.	Sum	Sum Sq. Dev.	Obs.
Variance of Currency :													
	Brazil	20,2029	17,9864	71,7389	10,9714	9,1015	2,4022	11,1080	525,5306	0,0000	2868,8086	11680,0114	143
	Russia	41,7655	23,7078	247,1200	10,9936	45,6350	2,4494	8,9438	353,4851	0,0000	5972,4703	295722,9353	143
	India	4,6084	2,9263	16,4057	1,6307	3,6654	1,6787	4,8014	85,8892	0,0000	654,3959	1894,3267	143
	China	1,3543	1,0910	3,8375	0,3662	0,8559	1,0806	3,6105	30,0526	0,0000	193,6683	104,0150	143
	South Africa	8,5983	5,6156	44,0880	-1,1945	8,2574	1,5968	5,6159	100,8320	0,0000	1220,9576	9614,0028	143
Interest Differential:													
	Brazil	4,7085	4,6500	11,7300	-1,7500	3,0059	0,0287	2,4292	1,9885	0,3700	682,7300	1301,1439	145
	Russia	2,9779	3,3400	18,5000	-4,9300	3,2353	0,2539	6,0702	58,5068	0,0000	431,8000	1507,2682	145
	India	1,5041	1,5400	6,6500	-3,9300	2,6480	-0,0248	2,0969	4,9424	0,0845	218,1000	1009,6985	145
	China	4,3179	3,9500	11,1000	-0,3000	2,3147	0,7222	3,5866	14,6844	0,0006	626,1000	771,5484	145
	South Africa	1,9731	1,6500	6,3500	-0,1500	1,2662	1,2675	4,7848	58,0708	0,0000	286,1000	230,8551	145
Oil		4,1855	4,1924	4,7421	2,9360	0,3491	-0,5841	3,3111	8,8301	0,0121	606,8981	17,5487	145
Gold		7,2917	7,2408	7,5959	6,9671	0,1804	0,1442	1,5786	12,7095	0,0017	1057,2996	4,6851	145
GPR:													
	Brazil	-3,6607	-3,1523	-1,3139	-13,8155	2,4241	-3,5050	15,1370	1186,8791	0,0000	-530,7960	846,1622	145
	Russia	-0,0561	-0,1334	1,7196	-1,2246	0,5628	0,6461	3,1749	10,2716	0,0059	-8,1358	45,6057	145
	India	-1,7405	-1,6841	-0,6496	-3,4769	0,5201	-0,3250	3,0773	2,5884	0,2741	-252,3768	38,9568	145
	China	-0,5090	-0,5575	0,6019	-1,4024	0,4336	0,1606	2,5532	1,8295	0,4006	-73,8046	27,0710	145
	South Africa	-4,6115	-3,4379	-1,6844	-13,8155	3,5364	-2,1296	5,8229	157,7411	0,0000	-668,6739	1800,8457	145
	USA	1,0010	0,9661	1,7926	0,5159	0,2316	0,5484	3,2228	7,5686	0,0227	145,1466	7,7269	145
EPU:													
	Brazil	5,2146	5,2088	6,5176	4,1366	0,4495	0,0755	3,0101	0,1382	0,9332	756,1132	29,0991	145
	Russia	5,4739	5,5054	6,8712	3,5996	0,6018	-0,2669	3,0798	1,7597	0,4149	793,7179	52,1578	145
	India	4,4168	4,3661	5,6479	3,1507	0,4805	0,2310	2,8006	1,5298	0,4654	640,4389	33,2439	145
	China	5,6331	5,6643	6,7476	4,3319	0,6278	-0,2587	1,8816	9,1735	0,0102	816,7998	56,7585	145
	USA	5,0296	5,0409	6,2225	4,1570	0,3736	0,4951	3,4266	7,0235	0,0298	729,2953	20,1041	145
Economy Openness:													
	Brazil	21,1021	20,4278	31,5929	12,8619	3,8065	0,5542	3,0104	7,4238	0,0244	3059,8037	2086,4803	145
	Russia	39,8842	38,5693	55,5364	22,1178	8,4607	0,0236	1,7986	8,7333	0,0127	5783,2044	10308,1318	145
	India	32,7697	31,1110	47,7952	15,0640	6,2441	0,2608	2,6838	2,2479	0,3250	4751,5996	5614,4317	145
	China	44,9489	44,1320	58,7963	21,7708	6,1515	-0,0341	3,5229	1,6798	0,4317	6517,5930	5449,1011	145
	South Africa	53,2515	51,5965	74,8625	27,4201	9,9498	-0,1316	2,5336	1,7330	0,4204	7721,4636	14255,7731	145
Foreign Reserves:													
	Brazil	5,8577	5,8754	5,9353	5,6831	0,0601	-1,1733	3,6283	35,6551	0,0000	849,3691	0,5199	145
	Russia	6,1960	6,2375	6,4522	5,8679	0,1655	-0,4222	1,9925	10,4396	0,0054	898,4207	3,9464	145
	India	6,0052	5,9748	6,4646	5,6186	0,2647	0,3183	1,7675	11,6260	0,0030	870,7580	10,0914	145
	China	8,0956	8,0703	8,2924	8,0058	0,0774	1,2753	3,3751	40,1537	0,0000	1173,8673	0,8628	145
	South Africa	3,8149	3,7938	3,9947	3,6996	0,0790	0,8220	2,7017	16,7495	0,0002	549,3490	0,8917	145
Stock Market Index:													
	Brazil	11,2140	11,1840	11,7504	10,6067	0,3322	0,0668	1,5051	13,6102	0,0011	1626,0251	15,8961	145
	Russia	7,6463	7,6500	8,3309	7,1746	0,3112	0,2694	2,0726	6,9492	0,0310	1108,7159	13,9464	145
	India	10,3856	10,3650	11,1054	9,6457	0,4014	0,0976	2,0248	5,9760	0,0504	1505,9088	23,1981	145
	China	8,1393	8,1969	8,5852	7,6684	0,2543	-0,3159	2,0934	7,3770	0,0250	1180,1993	9,3136	145
	South Africa	10,8800	10,8845	11,2832	10,2980	0,2222	-0,4296	2,9617	4,4696	0,1070	1577,6008	7,1087	145
Trading Volume :													
	Brazil	13,7317	13,8215	15,1014	11,8138	0,8134	-0,3494	2,3841	5,2425	0,0727	1991,0963	95,2640	145
	Russia	13,3365	13,5478	14,5046	9,4733	0,7878	-1,2630	5,7499	84,2353	0,0000	1933,7894	89,3677	145
	India	10,9782	10,9888	12,9044	10,0037	0,6290	0,3672	2,4592	5,0259	0,0810	1591,8456	56,9713	145
	China	10,8600	10,7612	12,5811	9,3264	0,7918	0,2741	2,1974	5,7075	0,0576	1574,6960	90,2873	145
	South Africa	13,9529	13,9682	15,2652	12,4895	0,6686	-0,1607	2,3955	2,8317	0,2427	2023,1684	64,3688	145

Interest differentials with the USA: Brazil and China have the highest interest differentials with the US, while India and South Africa have the smallest interest differentials with the US. Russia's interest rate differentials have the most volatility, varying from -4,3% to 18,5%. All the interest differentials are kurtosis. Due to the sovereign risk premium, the interest differential for the emerging economies is believed to have a higher interest rate than the US, implying they should skew to the right. However, the Indian series shows almost no skewness. Only Brazil and India's series are normally distributed.

Oil Price in logarithm terms: The oil price has skewness to the left, indicating the existence of an extremely low oil price. Historically, there was a low oil price in February 2020 during the COVID-19 pandemic. The oil price shows kurtosis and non-normality.

Gold price in logarithm term: The gold price also shows kurtosis, skewness, and non-normality. But the skewness is to the right, indicating the existence of an extremely high gold price in line with gold's nature of a "safety haven" in a crisis. Compared to oil, gold's price volatility is much smaller and almost half of that of oil.

GPR in logarithm term: The USA has the highest geopolitical risk, while Russia's and South Africa's GPR show the highest volatility. The GPRs are all skewed and all with kurtosis. Only the GPR of India and China show normality.

EPU in logarithm term: The EPU for all the countries are similar. Comparatively, China has the highest EPU, followed by Russia. These two nations also have the highest EPU volatility. Skewness of China and Russia's EPU are both negative, indicating some extremely small uncertainty index. India, Brazil and the USA have normal distributed EPUs.

Economy openness: South Africa has the highest economy openness while Brazil has the most closed economy. South Africa has the highest standard

deviation in its time series, while Brazil has the lowest. China and South Africa's openness is skewed to the left. Only China, India and South Africa's series have the normality.

Foreign reserves in logarithm term: China has the highest foreign reserves while South Africa has the lowest reserves. All the countries' foreign reserves have skewness, kurtosis, and non-normality. Brazil and Russia have negative skewness, indicating extremely small figures. **Stock market index in logarithm term:** Brazil has the highest stock market index price while Russia has the lowest. India has the highest stock market volatility while the South African market has the lowest volatility. China and South Africa have negative skewness, indicating the existence of extremely low market prices. All the markets show kurtosis and non-normality, except for the South African stock market that has a normal distribution.

Trading volumes in logarithm term: South Africa and Brazil show the highest trading volumes, while Brazil has the highest volume volatility. Russia has the highest kurtosis indicating the fat tail. The skewness for Russia is also the highest. The negative Russian trading volumes skewness indicates extremely low trading volumes that may be related to the international financial sanctions after the outbreak of the Russia-Ukraine war. The trading volumes of Brazil, India, and China have normality.

4.3 Stationarity tests

The precondition for the ARDL model is to have the variables be I(0) or I(1) stationary. The study conducted the Augmented Dicky Fuller (ADF) and Phillips-Perron (PP) unit root tests for stationarity. The Phillips-Perron method is added to the research since the PP method uses a non-parametric method to adjust for serial correlation and endogeneity of regressors, thereby preventing the loss of observations implied by the ADF test (Adu & Marbuah, 2011). Moreover, the

PP method allows for the possibility of heteroskedastic error terms (Adu & Marbuah, 2011; Hamilton, 1994;).

The unit root tests' results are presented in **Table 4.3**. In the ADF and PP unit root tests, in level, or at I(0), the t statistic in the parenthesis should be significant at 5%, to reject the null hypothesis of an unit root or non-stationary, and thus confirm the stationarity. If non-stationarity is found at I(0) level, the further test in the first difference, or I(1), was conducted to check whether the p value of t statistic is 5% significant, in other words, if the variable is stationary at I(1) level. The ADF and PP unit root tests in the research confirm that all the variables are stationary at I (0) or I (1).

Table 4.3: Unit root tests for variables

Variables		Augmented Dickey Fuller Unit Root Test						Phillips-Perron Unit Root Test					
		I(0)			I(1)			I(0)			I(1)		
		constant	constant &trend	none	constant	constant & trend	none	constant	constant &trend	none	constant	constant &trend	none
Variance of Currency													
	Brazil	(-6,8874)***	(-6,8686)***	(-1,5672)				(-6,8466)***	(-6,8281)***	(-1,9402)**			
	Russia	(-3,5555)***	(-3,6690)**	(-2,4663)**				(-3,5531)***	(-3,5863)**	(-2,4222)**			
	India	(-3,7268)***	(-6,6046)***	(-0,2920)				(-4,9361)***	(-6,4292)***	(-2,2355)**			
	China	(-1,8844)	(-2,3553)	(-1,0558)	(-7,503)***	(-7,506)***	(-7,5294)***	(-3,0779)**	(-3,6861)**	(-1,8974)*			
	South Africa	(-0,3102)	(-2,7046)	(-0,8781)	(-0,5046)***	(-5,1239)***	(-4,7757)***	(-1,8516)	(-3,5753)**	(-0,3919)			
Interest Differential:													
	Brazil	(-1,9285)	(-,82363)	(-0,6138)	(-4,3987)***	(-4,3578)***	(-4,4201)***	(-2,1269)	(-2,1007)	(-1,3352)	(-9,7516)***	(-9,7512)***	(-9,7746)***
	Russia	(-3,2723)***	(-3,2785)*	(-2,3617)**				(-3,2723)**	(-3,2785)*	(-2,4165)**			
	India	(-2,6395)*	(-2,6276)	(-1,9813)**				(-2,4486)	(-2,4446)	(-2,1576)**			
	China	(-2,6312)*	(-2,6999)	(-1,2265)	(-3,1034)**	(-3,1000)	(-3,1123)***	(-1,8166)	(-1,7801)	(-0,9978)	(-11,9805)***	(-11,9604)***	(-12,0127)***
	South Africa	(-2,4055)	(-4,1808)***	(-1,0213)				(-2,4877)	(-3,0527)	(-1,6187)*	(-11,8986)***	(-11,8513)***	(-11,9306)***
Oil		(-2,1855)	(-2,0192)	(-0,2247)	(-9,2627)***	(-9,2922)***	(-9,2957)***	(-2,0857)	(-1,9949)	(-0,0341)	(-10,2487)***	(-10,4536)***	(-10,2978)***
Gold		(-1,2044)	(-2,0212)	(-0,2205)	(-12,7753)***	(-12,8985)***	(-12,8196)***	(-1,1125)	(-1,91754)	(-0,2505)	(-12,8201)***	(-13,0294)***	(-12,8657)***
GPR:													
	Brazil	(-2,2397)	(-4,0087)**	(-1,0588)				(-11,5971)***	(-13,3397)***	(-5,0873)***			
	Russia	(-2,9469)**	(-3,3811)*	(-2,9818)***				(-3,9162)***	(-4,5265)***	(-3,9114)***			
	India	(-4,6616)***	(-8,3496)***	(-0,5776)				(-8,0431)***	(-8,3739)***	(-1,2229)			
	China	(-2,6279)*	(-3,9736)**	(-1,6544)*				(-6,3620)***	(-7,7800)***	(-3,3054)**			
	South Africa	(-10,2341)***	(-10,1991)***	(-1,2706)				(-10,4045)***	(-10,3721)***	(-5,4230)***			
	USA	(-3,7503)***	(-3,8558)**	(-0,1451)				(-5,2369)***	(-5,3759)***	(-0,1348)			
EPU:													
	Brazil	(-4,6923)***	(-4,8022)***	(-0,1177)				(-6,2687)***	(-6,4955)***	(-0,2378)			
	Russia	(-2,3462)	(-6,2374)***	(-0,2618)				(-7,6142)***	(-9,9401)***	(0,0025)			
	India	(-3,8534)***	(-6,0906)***	(-1,2661)				(-4,6706)***	(-6,0421)***	(-1,0423)			
	China	(-1,0172)	(-2,5962)	(-0,6681)	(5,5799)***	(-7,3939)***	(-5,5183)***	(-1,9053)	(4,4382)***	(-0,4249)			
	USA	(-2,2399)	(-3,0695)	(-0,3200)	(-9,1255)***	(-9,0938)***	(-9,1564)***	(-4,7816)***	(-5,5631)***	(-0,5969)			
Economy Openness:													
	Brazil	(-2,3117)	(-2,6755)	(-0,7228)	(-2,4258)	(-2,3592)	(-2,4322)**	(-2,4271)	(-2,9824)	(-0,3280)	(-15,6642)***	(-16,0488)***	(-15,7166)***
	Russia	(-2,0148)	(-1,8104)	(-0,8329)	(-13,9287)***	(-13,9731)***	(-13,9623)***	(-2,0016)	(-1,8063)	(-0,8081)	(-14,1088)***	(-14,2610)***	(-14,1373)***
	India	(-2,4061)	(-2,4160)	(-1,0076)	(-3,0286)**	(-3,1938)*	(-2,9679)***	(-2,4803)	(-2,4207)	(-1,1416)	(-16,9407)***	(-17,3786)***	(-16,7932)***
	China	(-2,1697)	(-1,9915)	(-0,9112)	(-2,7569)*	(-3,5329)**	(-2,6772)***	(-4,0853)***	(-4,9871)***	(-1,0331)			
	South Africa	(-2,7030)*	(-2,7998)	(-1,3403)	(-1,2731)	(-1,0083)	(-1,2024)	(-2,9766)**	(-2,8260)	(-1,2533)	(-15,4775)***	(-15,4286)***	(-15,4419)***
Foreign Reserves:													
	Brazil	(-0,3727)	(-1,913)	(-0,6701)	(-10,8575)***	(-11,0240)***	(-10,8582)***	(-0,6657)	(-2,0641)	(-0,5899)	(-10,9142)***	(-11,0646)***	(-10,9441)***
	Russia	(-1,1200)	(-1,5371)	(-0,3085)	(-4,5992)***	(-5,6738)***	(-4,6017)***	(-0,9017)	(-1,5688)	(-0,2462)	(-10,1467)***	(-10,2161)***	(-10,1718)***
	India	(-0,0687)	(-3,1201)	(-1,8602)	(-8,0393)***	(-8,0655)***	(-7,7556)***	(-0,1306)	(-2,6618)	(-2,1236)	(-8,1607)***	(-8,1958)***	(-7,9560)***
	China	(-1,3894)	(-2,7767)	(-0,1211)	(-6,0484)***	(-6,0720)***	(-6,0672)***	(-1,2986)	(-1,9576)	(-0,1424)	(-9,6083)***	(-9,6012)***	(-9,6319)***
	South Africa	(-0,5812)	(-2,2122)	(-0,9790)	(-14,3641)***	(-7,9382)***	(-14,3309)***	(-0,5164)	(-2,2699)	(-1,4387)	(-16,2884)***	(-19,5056)***	(-15,2793)***
Stock Market Index:													
	Brazil	(-0,8003)	(-3,0576)	(-1,0045)	(-9,5323)***	(-9,5133)***	(-9,4748)***	(-0,7231)	(-2,3998)	(-1,5634)	(-11,9182)***	(-12,0880)***	(-11,4089)***
	Russia	(-1,1954)	(-3,2775)*	(-1,1077)	(-4,6240)***	(-4,6019)***	(-4,5264)***	(-1,2496)	(-2,6069)	(-1,0763)	(-12,8395)***	(-12,7991)***	(-12,7871)***
	India	(-0,6167)	(-3,3381)*	(-2,3949)	(-13,1473)***	(-13,1066)***	(-12,6796)***	(-0,4711)	(-3,3381)*	(3,0188)	(-13,3722)***	(-13,3273)***	(-12,6798)***
	China	(-1,8074)	(-2,6988)	(0,3003)	(-10,5759)***	(-10,5481)***	(-10,6029)***	(-1,7723)	(-2,4772)	(0,0412)	(-10,5146)***	(-10,4833)***	(-10,5452)***
	South Africa	(-2,2659)	(-3,3114)*	(1,8061)	(-13,2879)***	(-13,2946)***	(-13,0426)***	(-2,2348)	(-3,2171)*	(2,3608)	(-13,8375)***	(-13,9703)***	(-13,1483)***
Trading Volume (-1)													
	Brazil	(-1,5065)	(-4,1444)***	(-0,8478)				(-2,6020)	(-3,8355)**	(-0,7579)			
	Russia	(-2,6335)*	(-2,7746)	(-0,1409)	(-12,1290)***	(-12,1249)***	(-12,1658)***	(-3,2276)**	(-3,6063)**	(-0,4986)			
	India	(-2,4600)	(-4,9305)***	(-0,4294)				(3,2575)**	(-4,8177)***	(-0,5392)			
	China	(-1,2781)	(-1,3278)	(-0,2103)	(-3,9746)***	(-4,0249)**	(-3,9863)***	(-2,8459)*	(-3,5944)**	(0,3021)			
	South Africa	(-1,7696)	(-3,0140)	(-0,8318)	(-4,3558)***	(-4,4048)***	(-4,2787)***	(-1,7020)	(-3,1057)	(0,6477)	(-13,2768)***	(-13,2414)***	(-13,2822)***

Note: ***, **, *represent significance at 1%, 5% and 10% levels. Figures in the parenthesis are t statistics.

4.4 ARDL Model estimation

To obtain the optimal lags in the model, the study minimised the Akaike Information criteria (AIC) in the estimation. The estimation results of the optimal lags and coefficients of the parameters are presented in **Table 4.4**.

The estimation process started from the F bounds tests proposed by Pesaran et al. (2001). For all individual models, long run co-integration amongst the variables was confirmed, by F-statistics being above the upper bounds at the 5% significance level during the F bounds tests.

In general, the ARDL model estimations are good. Most of the R squared figures are above 50%, illustrating a good explaining and predicting power. Dubin-Watson statistics are closed to 2,0, showing models are not suffering from serial corelation problems. The F statistics are significant at 5%, showing the regressions provide good fit.

The error correction terms for the five models are always significant with the right sign, illustrated by the coefficients of the error correction terms are negative and having test statistics significant at 5% level. The speed of adjustment for Brazil and South Africa are comparatively high, both over 50%. The Real's volatility bounces back to the long run equilibrium at 59,9% in one month after the shock. And the Rand's volatility bounces back to the long-term equilibrium at 58,5% in one month after the shock. It implies that the two models have a much faster speed of adjusting to their long run equilibriums during one term.

The real interest rate differentials with USA play an important role in explaining the currency volatility of China in the long run, and Russia in the short run, illustrated by the coefficients at 5% statistical significance level. One base point of increase in Chinese interest differential with USA, causes a 0,2 unit of decrease of the Chinese RMB's volatility. For Russia, the signs of the

Table 4.4: ARDL Model Estimation Results

	Brazil		Russia		India		China		South Africa	
Long Run Cointegration Estimation Result:										
Interest Differential	-0,9937	[-1,4146]			-0,1295	[-0,8410]	-0,2002	[-3,8280]***	-0,3675	[-0,4676]
Interest Differential(-1)			-1,3416	[-0,7515]						
Oil	-5,5207	[-0,8162]								
Oil (-1)			-59,7427	[-1,8450]*	4,0232	[1,9326]*	1,9462	[2,9885]***	8,7119	[1,4702]
Gold(-1)	-		-		8,3439	[2,3035]**	-		-	
GPR-domestic	0,2155	[0,4782]								
GPR-domestic (-1)					-0,3437	[-0,3666]	-1,1192	[-2,3432]**	-1,4316	[-2,3255]**
GPR-USA (-1)	10,1947	[1,1463]	57,2514	[1,5956]	-6,2699	[-2,6294]***	1,5798	[1,8651]*	3,5326	[0,6406]
EPU-domestic	4,0961	[1,2536]			1,2268	[1,2231]	0,5941	[-1,6040]		
EPU-domestic (-1)			9,8661	[0,8613]						
EPU-USA			-0,6617	[-0,0389]					3,6257	[0,9923]
EPU-USA (-1)	-9,6764	[-1,6149]			-1,8867	[-1,1196]	0,3895	[1,0775]		
Economy Openness					-0,1950	[-1,3426]	-0,0117	[-0,4944]		
Economy Openness (-1)	-0,6080	[-0,8369]	2,4635	[1,7007]*					-0,4029	[-1,7391]*
Foreign Reserves	100,3275	[0,3958]**	-33,2416	[-0,5964]			-3,1760	[-1,8316]*		
Foreign Reserves (-1)					-9,7356	[-2,9612]***				
Stock Market					-		0,9442	[1,1515]	-3,2091	[-1,1869]
Stock Market (-1)	19,8874	[1,3921]	39,2145	[1,248491]	-					
Trading volumes (-1)	1,4642	[0,3958]			0,1945	[0,2593]	-0,5527	[-2,2714]**	0,0354	[0,0153]
Error Correction Term										
	-0,5990	[-8,6469]***	-0,4322	[-7,2490]***	-0,2590	[-6,4734]***	-0,2444	[-7,3924]***	-0,5854	[-6,7835]***
ARDL Short Run Estimation Result:										
ΔVariance (-1)			0,1946	[2,8027]***	0,0736	[1,0012]	-0,1764	[-2,3681]**	0,1038	[1,1403]
ΔVariance (-2)					0,1836	[2,6015]**	-0,1254	[-1,7230]*	0,2287	[2,6501]***
ΔVariance (-3)					0,0559	[0,8102]			0,2659	[3,2076]***
ΔVariance (-4)					0,2495	[3,7941]***				
ΔInterest Differential			-2,6747	[-2,5038]**						
ΔInterest Differential (-1)			-1,0011	[-0,9021]						
ΔInterest Differential (-2)			0,7178	[0,6820]						
ΔInterest Differential (-3)			-3,3712	[-3,0898]***						
ΔInterest Differential (-4)			4,0563	[3,8848]***						
ΔOil			-60,8996	[-4,5188]***	0,0232	[0,0394]	0,3136	[2,1585]**	11,9167	[2,8577]***
ΔOil (-1)							-0,2922	[-2,0172]**	-8,6183	[2,0511]**
ΔOil (-2)									7,8879	[1,7917]*
ΔGold	-		-		-0,4291	[-0,2355]	-		-	
ΔGold (-1)	-		-		-0,3088	[-0,1694]	-		-	
ΔGold (-2)					8,1272	[4,5496]***				
ΔGPR-domestic					0,1315	[0,9885]	-0,1145	[-2,1107]**	0,0672	[0,5062]
ΔGPR-domestic (-1)					-0,5415	[-3,7806]***			0,6746	[3,6756]***
ΔGPR-domestic (-2)									0,9092	[4,9443]***
ΔGPR-domestic (-3)									0,6187	[3,5568]***
ΔGPR-domestic (-4)									0,5007	[3,6227]***
ΔGPR-US	0,1372	[0,0403]	-13,2828	[-1,4125]	-0,8003	[-1,969]*	-0,0683	[-0,6336]	-4,4737	[-1,710]*
ΔGPR-US (-1)	-8,3869	[-2,3890]	-38,0540	[-3,5841]***	1,6682	[3,4685]***	-0,3981	[-3,8696]***	-7,9753	[-2,9527]***
ΔGPR-US (-2)			-51,3155	[-4,6469]***	0,7818	[1,8884]*	-0,2889	[-2,8358]***		
ΔGPR-US (-3)			-37,1054	[-3,1799]***						
ΔGPR-US (-4)			-35,0769	[-3,4332]***						
ΔEPU-domestic			9,1191	[3,3914]***						
ΔEPU-USA	0,1470	[0,0651]			0,6427	[2,2461]**	-0,0214	[-0,3579]		
ΔEPU-USA (-1)	11,8304	[4,9904]***			0,7753	[2,8663]***				
ΔEPU-USA (-2)	9,0265	[3,6755]***								
ΔEPU-USA (-3)	3,6034	[1,4648]								
ΔEconomy Openness	-0,2885	[-0,7792]	-1,1676	[-1,7296]*					-0,3811	[-3,7331]***
ΔEconomy Openness (-1)	1,3941	[3,6262]***	-1,3105	[-1,8426]*					-0,0376	[-,0,3629]
ΔEconomy Openness (-2)	0,8264	[2,1846]**	-1,3946	[-2,0875]**					-0,0110	[-0,1077]
ΔEconomy Openness (-3)									0,3406	[2,9907]***
ΔEconomy Openness (-4)									0,2448	[2,3111]**
ΔForeign Reserves			-86,4566	[-0,9652]	0,5082	[0,1022]				
ΔForeign Reserves (-1)			-111,8946	[-1,1865]	-10,8502	[-1,9836]**				
ΔForeign Reserves (-2)			-40,0874	[-0,4163]	17,3510	[-3,4122]***				
ΔForeign Reserves (-3)			-315,3275	[-3,3373]***						
ΔForeign Reserves (-4)			-248,5864	[-2,5802]**						
ΔStock Market Index	22,5145	[2,4513]**	-44,7129	[-1,3740]	-					
ΔStock Market Index (-1)	-24,1970	[-2,5184]**	-50,9284	[-1,6353]	-					
ΔStock Market Index (-2)	17,4473	[1,7795]*	-17,7532	[-0,5748]	-					
ΔStock Market Index (-3)			-72,8775	[-2,3229]**						
ΔTrading Volume	0,1727	[0,0750]			-0,0045	[-0,0223]	-0,0104	[-2,3224]	4,5713	[2,0587]**
ΔTrading Volume (-1)	6,0545	[2,5790]**			-0,5023	[-2,5480]**	0,1570	[3,1350]**	1,3832	[0,6170]
ΔTrading Volume(-2)	4,0891	[1,7891]*					0,0780	[1,6890]*	6,8207	[3,0704]***
Constant	263,4232	[8,6364]***					2,4380	[7,2910]***		
Trend	-0,1377	[-6,5237]***					0,0043	[6,6814]***		
R Squared	**0,5443**		**0,6213**		**0,5153**		**0,3771**		**0,5290**	
F Bounds Test	**6,2446**	**(cointegration**	**4,8400**	**(cointegration**	**3,4811**	**(cointegration)**	**4,5705**	**(cointegration)**	**4,7603**	**(cointegration)**
F statistic	**8,6408*** **		**7,4805*** **		**6,1666*** **		**5,4059*** **		**6,2041*** **	
Durbin Watson statistic	**2,0110**		**2,0784**		**1,9856**		**2,0033**		**2,1124**	

Note: ***, **, *represent significance at 1%, 5% and 10% levels. The figures in parentheses are the t-statistics.

impact are different in the different lags. One base point of current increase in Russian interest differential with USA, causes 2,7 unit of decrease in Ruble's volatility. However, one base point of interest differential increase in the last four month, increase the current Ruble's volatility by 4.1 units.

Commodity price fluctuation is a significant risk source of the BRICS currencies. China and India are the world's top two and third-largest net consumers of crude oil, while Russia is the world's second-largest net exporter of oil. The ARDL results demonstrate oil price changes have significant impacts on the Ruble, RMB, and Rand's fluctuation. One dollar increase in the oil price (logarithm term) generally causes the Ruble's volatility to decrease 60,89 units. One dollar increase in the oil price (logarithm term) drives the Rand's volatility to 11,92 units increase immediately, but also leads the next month's volatility to a 8,62 units of decrease. The oil price affects the RMB's volatility both in the short run and the long run. One dollar increase in the oil price (logarithm term) leads to 1,94 unit increase of RMB's variance in long run, and 0,32 unit increase of RMB's volatility at current month. South Africa, as an important gold exporter, is not affected significantly by the gold price fluctuation in terms of the Rand's volatility. The only currency's volatility that responds to the gold price movement is the Indian Rupee, both in the long run and in the short run. Therefore, the study uses gold price and oil price representing the commodity price as a regressor for the Indian Rupee, while the oil price as the regressor for the rest of the currencies. The study confirms one dollar increase in gold price (logarithm term) leads to 8,34 unit of increase in Rupee's volatility in long-run, and 8,13 unit increase of Rupee's volatility in two months. It could be explained by the gold importing in India. India was ranked the 2nd largest gold consumer in the world, and in 2023-2024 it imported $45,54 billion of gold.

US geopolitical risk and economic policy uncertainty have spillover effects on the five currencies, but the impacts are heterogeneous in nature. The Indian Rupee suffers from the US's geopolitical risk change in the long run. One unit of US geopolitical risk index increase drives the Rupee's volatility to decrease 6,27 units. The currency volatility of Russia, India, China and South Africa are affected by the US geopolitical risk change in the short run. One unit of US geopolitical risk index increase drives the Rupee's volatility to increase 1,66 units in next month. But for South African Rand, Russian Ruble or Chinese RMB, the affect is with a negative sign. One unit of US geopolitical risk index increase leads 0,40 units of decrease of RMB's volatility in the next month and 8 units of decrease of Rand's volatility in the next month. Noticeably the US geopolitical risk affects the Ruble's volatility consistently at lag 1, 2, 3 and 4, as well as with great magnitude. One unit of US geopolitical risk increase causes 38,05 units of Ruble's volatility decrease in the next month, 51,32 units of decrease in the third month, 37,11 units of decrease in the fourth month, and 35,08 units of decrease in the fifth month.

On the other hand, the US EPU does not affect the five-currency volatility in the long term, but affect the volatility of the Real and the Rupee in the short run, since both are US's important trade partners. One unit of the US Economic Political uncertainty increase, leads to 11,82 units of Real's volatility increase in the next month and 9,02 increase in two months. Comparatively, impact on Indian Rupee is much smaller in magnitude, but more prompt. One unit increase of the US Economic Political Uncertainty, leads to 0,64 units of Rupee's volatility increase in the current month and 0,78 increase in the next month. Similarly, the study by Xavier and Vasconcelos (2019) indicates that the USA EPU plays a more important role than the local EPU in explaining the Brazilian stock market's returns, in terms of momentum effects.

The local geopolitical risks of India, China and South Africa define their

currency volatility. The impact on Rand's volatility is consistent. One unit increase of domestic geopolitical risks index increases the Rand's volatility by 0,67 units in the coming month, 0,91 units in two months' time, 0,62 units in three months' time, and 0,5 units in four months' time. Interestingly, the impacts of domestic geopolitical risks to RMB and Rupee are both negative, which means the increase of local geopolitical risks decreases the currency volatilities in China and India.

The country specific EPU affects the Russian Ruble in the short term. One unit of the local EPU index increase drives 9,12 units of increase in Ruble's current volatility. For the other countries, the local EPU has no significant impact on currency volatility.

The **economy openness** explains the currency risk in South Africa significantly in the short term and weakly in the long run. South Africa is the smallest also the most open economy in BRICS and, for the long run and the current term, the impacts are negative. One unit of economy openness increase drives 0,38 units of decrease in the Rand's volatility at current term, as well as 0,34 units of increase in three months' time and 0,24 units of increase in four months' time. This finding aligns with the studies of Hau (2002) and Obstfeld and Rogoff (2000) that claim that exchange rate volatility and economic openness are inversely related, since more imported goods provide a channel for a quick adjustment of the domestic aggregate price level. In turn, this reduces the effects of a money supply or shock on the household balance, therefore reducing the effect on the exchange rate. Similarly, this study observed a significant and negative impact of economy openness on the Ruble's volatility for different lags in Russia. However, on the contrary, the economy openness of three and four lags period has a positive impact on the South African Rand's volatility.

Foreign reserves might be an indicator to explain the market confidence in a currency and the intervention ability of the central banks, therefore, is crucial to

the currency's volatility. Results show that changes in foreign reserves are a predictor for Russian and Indian currencies in the short run. One unit of foreign reserve increase causes 315 units decease in Ruble's volatility in three months' time, and 249 units of volatility decrease in four months' time. The magnitudes are great. One unit of foreign reserve increase caused 10,85 units decrease in Rupee's volatility in next month, and 17,35 units increase in two months' time. In the long run, foreign reserves explain Brazil, India and China's currency volatility changes. For South Africa, the foreign reserve movement is not a significant predictor of both the short and the long run.

The Stock market index is not affecting the currency volatilities in long run, but it is a significant determinant of Indian and Russian currency volatility in short run. One unit of stock market index increase leads to 22,52 units of the Real's volatility increase immediately and 24,20 units of volatility decrease in the next month. Comparatively, the impact on the Ruble is postponed and greater. One unit of stock market index increase drives to 72,88 units of the Ruble's volatility decrease in the three months' time.

Foreign exchange trading volume has a long run influence on the RMB's volatility, and affects the exchange volatility for Brazil, India, China and South Africa in the short run.

4.5 Evolution trend

The Cumulative Dynamic Multiplier graphs show that only China demonstrates the obvious shock evolution in the EPU and GPR while the EPU and GPR of the USA impacts on currency variance. The impacts of US and oil price on RMB volatility is increasing, the impact of Chinese economic policy uncertainty is also accelerating, while the impact of interest differentials is declining. The 15-month dynamic multipliers of the Chinese ARDL model are shown in **Figure 4.5**.

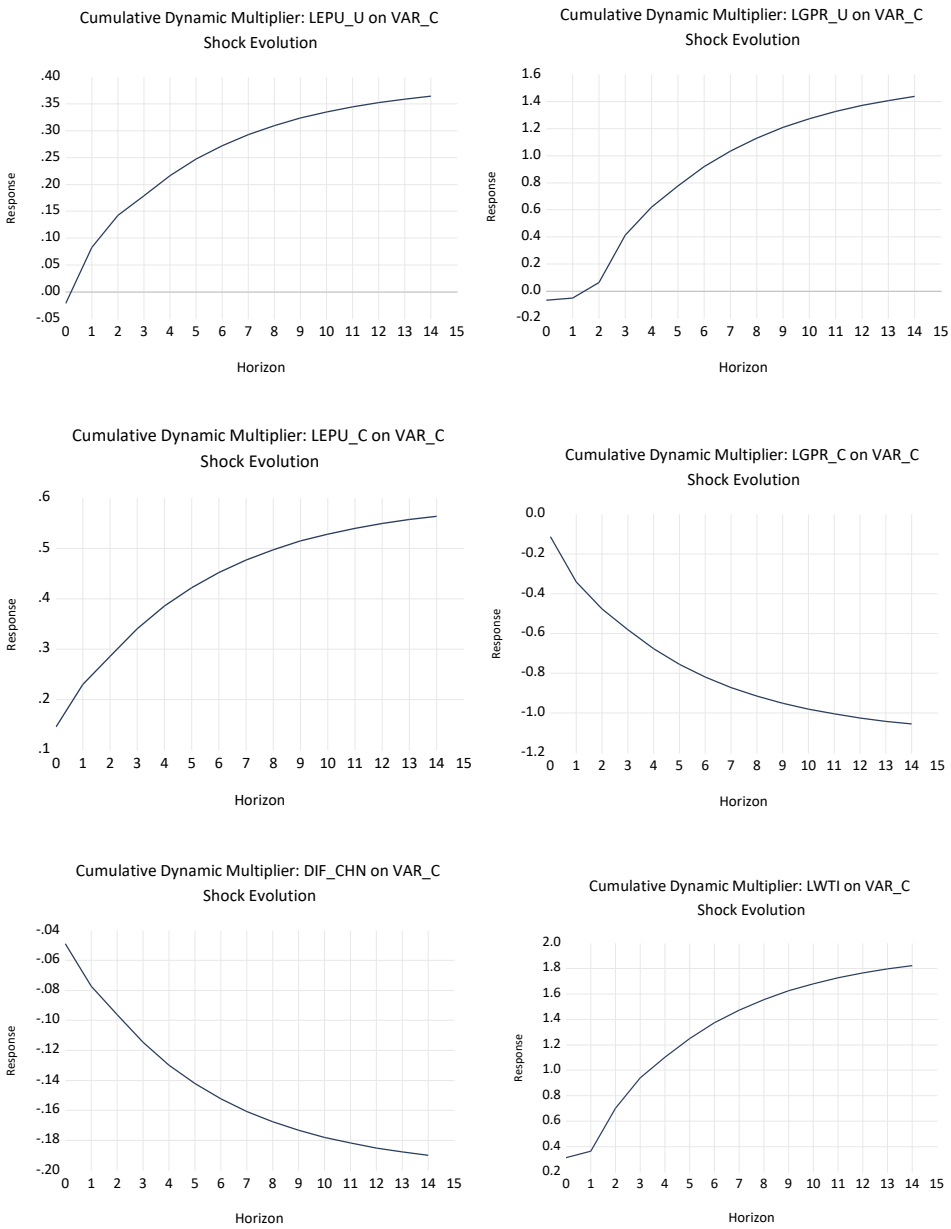

Figure 4.5: Dynamic multiplier of Chinese ARDL Model

4.6 Robustness tests

To observe the models' robustness, the residual tests were conducted. None of the models are suffered from serial correlations, however, some models suffered from heteroskedasticity except for South Africa. The serial correlation was tested by Breusch - Godfrey Serial Correlation LM Test. With the Observed R Squared figure has prob. of Chi-squares more than 0,05, we cannot reject the hypothesis of no serial correlation, and thus conclude none of the individual

ARDL models of BRICS are suffering from residual serial correlation.

On the other hand, Breusch-Pagan-Godfrey heteroskedasticity tests were conducted. With the Observed R Squared figure have prob. of Chi-squares less than 0,05, we reject the hypothesis of no heteroskedasticity. We confirm that except for South African model, the models are suffering from heteroskedasticity. The models' heteroskedasticity problem is further addressed by the Quantile Regression in **4.7**.

Additionally, none of the residual series were normally distributed, illustrated by the Jacque Bera statistics which are much higher than 3, and the p values are less than 0,05. **Table 4.5** shows the results of the above robustness tests.

Furthermore, the study conducted the CUSUM tests, which confirmed that all models were stable. The CUSUM tests results are presented in **Appendix C**.

Table 4.5: Robustness tests for residual serial correlation, heteroskedasticity and normality

	Brazil	**Russia**	**India**	**China**	**South Africa**
Breusch - Godfrey Serial Correlation LM Test:					
Obs*R-Squared	6,1879	5,0938	0,7904	0,9119	7,2221
Prob.Chi-Square	0,1856	0,1651	0,8518	0,8223	0,1246
Breusch-Pagan-Godfrey Heteroskedasticity Test:					
Obs*R-Squared	61,1188	54,9193	56,0726	63,6220	28,2536
Prob.Chi-Square	0,0002	0,0173	0,0038	0,0000	0,5570
Jarque Bera Normality Test:					
Jarque Bera Stat.	66,7929	33,4244	519,0349	168,0038	93,3562
P value	0,0000	0,0000	0,0000	0,0000	0,0000

4.7 Quantile regression

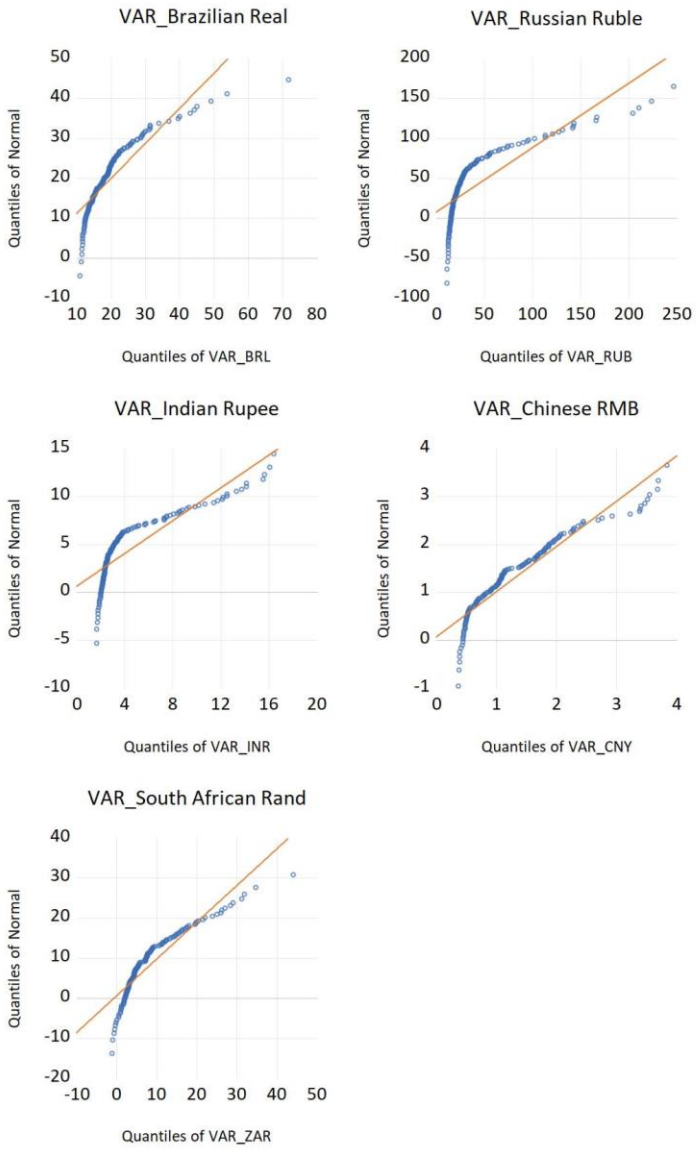

Figure 4.6：Quantiles of the currency variance of the BRICS countries

Figure 4.6 shows that all the currencies have significant tail behaviours. It would be valuable to further explore the QR method to closely observe the determination relationship at extreme conditions. It is also of great interest to the investors and regulators for better risk management and effective policy making, since, when volatility is at a high level, policy or investment responses are generally needed. The QR results are presented in **Table 4.6**.

Table 4.6: Quantile regression estimation result

	Brazil				Russia				India				China				South Africa			
	Bottom Quantile (10%)		Top Quantile(90%)		Bottom Quantile(10%)		Top Quantile(90%)		Bottom Quantile (10%)		Top Quantile (90%)		Bottom Quantile (10%		Top Quantile (90%)		Bottom Quantile (10%)		Top Quantile (90%)	
Long Run Cointegration Estimation Result:																				
Interest Differential	-0,21351	[-0,7176]	1,6339	[1,2288]					-0,1031	[-2,0979]**	-0,2649	[-2,1660]**	0,0012	[0,2406]	-0,0599	[-0,8406]	-0,0852	[-0,2280]	0,1082	[0,1113]
Interest Differential(-1)					-0,7072	[-1,1192]	-3,2169	[-0,6521]												
Oil	-0,71286	[-0,1588]	-33,7975	[-5,6024]***																
Oil (-1)					-15,5221	[-1,2323]	10,6940	[0,1253]	0,2224	[0,2882]	-0,2658	[-0,1102]	-0,0202	[-0,5594]	0,5874	[1,2694]	2,7129	[0,9355]	-11,5510	[-2,6210]***
Gold(-1)									5,3172	[5,3346]***	9,5383	[5,0102]***								
GPR-domestic	-0,09028	[-0,2865]	0,5677	[1,2530]	6,9924	[2,2035]**	10,4414	[0,4776]												
GPR-domestic (-1)									-0,2382	[-1,1003]	-1,0561	[-2,4997]**					-0,0293	[-0,1590]	-0,1741	[-0,4619]
GPR-USA (-1)	-1,10380	[-0,3532]	-0,3532	[-0,3532]	7,9509	[1,1914]	83,7630	[0,8565]	-0,0430	[-0,0729]	-0,8205	[-0,8988]	0,0173	[0,4279]	0,3172	[0,8738]	-1,7584	[-0,7819]	-19,8232	[-2,6456]***
EPU-domestic	1,14653	[0,8820]	-7,1742	[-1,5087]					0,4273	[1,7204]*	0,7270	[0,8932]	-0,0056	[-0,2426]	0,4145	[1,7870]*				
EPU-domestic (-1)					2,3833	[0,8888]	40,7325	[1,5848]												
EPU-USA					3,1927	[0,6568]	-0,7842	[-0,0095]									2,7905	[1,0368]	4,1406	[0,9357]
EPU-USA (-1)	-1,76877	[-0,6127]	3,1209	[0,5287]					0,3135	[1,1207]	1,8265	[2,3784]**	0,0034	[0,1454]	-0,0427	[-0,1419]				
Economy Openness									0,0590	[1,3616]	0,2907	[1,6532]	0,0000	[0,0002]	-0,0087	[-0,4356]				
Economy Openness (-1)	0,16961	[0,5908]	0,7764	[1,1680]	0,1108	[0,3430]	-2,0438	[-1,1004]									-0,1130	[-0,9051]	-0,0616	[-0,3660]
Foreign Reserves	-7,45425	[-0,2575]	-73,1675	[-1,6904]									0,0534	[0,4434]	-0,0021	[-0,0024]				
Foreign Reserves (-1)					21,5985	[1,1755]	74,9673	[0,3415]	-6,5796	[-5,4839]***	-14,2249	[-8,3935]***								
Stock Market	-1,52108	[-0,1429]	-15,2906	[-1,6350]									-0,0282	[-0,0281]	0,3569	[1,3825]	-2,1176	[-1,2624]	0,9646	[0,2381]
Stock Market (-1)					-11,9838	[-1,3663]	-82,4272	[-1,4494]												
Trading Volumes (-1)	1,51046	[0,8501]	5,7462	[1,4339]					-0,2437	[-1,1202]	0,1336	[0,2046]	-0,0025	[-0,1749]	-0,0355	[-0,3170]	0,4897	[0,2865]	4,1424	[1,8536]*
Constant	57,73094	[0,3890]	708,6131	[2,2898]**																
Short Run Estimation Result:																				
ΔVariance (-1)					0,1281	[1,035]	0,1230	[1,1530]	0,0119	[0,0630]	-0,0437	[-0,9959]	-0,0852	[-2,6157]**	0,0057	[0,0361]	-0,2501	[-3,7295]***	-0,1383	[-0,5068]
ΔVariance (-2)									0,0939	[0,7310]	-0,1018	[-1,2132]	-0,0743	[-1,2315]	-0,2502	[-3,4983]***	-0,2419	[-3,2822]***	0,5116	[1,6527]
ΔVariance (-3)									0,0072	[0,1167]	-0,1690	[-2,6268]***					-0,1052	[-1,3093]	0,1893	[1,2116]
ΔVariance (-4)									0,2634	[2,3418]**	0,1547	[0,8309]								
ΔInterest Differential					[-1,3639]	[-1,4155]	-0,8965	[-0,6111]												
ΔInterest Differential (-1)					[0,3487]	[0,1846]	-2,4762	[-1,7994]*												
ΔInterest Differential (-2)					[0,6157]	[0,2467]	1,1338	[0,5009]												
ΔInterest Differential (-3)					[-0,1964]	[-0,1546]	0,4486	[0,5099]												
ΔInterest Differential (-4)					[3,7312]	[1,8078]*	3,3668	[1,6879]*												
ΔOil					[-10,0877]	[-0,7569]	-19,7083	[-1,1539]	-0,1702	[-0,6057]	-0,4088	[-0,9359]	0,0615	[0,7322]	0,4435	[1,9908]**	-11,6144	[-3,8236]***	17,5214	[2,0398]**
ΔOil (-1)																	8,1368	[0,9578]	-6,6398	[-0,6920]
ΔOil (-2)																	-7,2965	[-1,5635]	14,1523	[1,2140]
ΔGold									0,0447	[0,0356]	0,3530	[0,4157]								
ΔGold (-1)									0,4186	[0,3651]	-1,0544	[-1,5205]								
ΔGold (-2)									4,2367	[2,9761]***	2,3170	[2,3172]**								
ΔGPR-domestic									-0,0788	[-1,0686]	-0,0116	[-0,1663]	-0,0180	[-0,3622]	-0,1324	[-1,5918]	0,1146	[0,8206]	0,1990	[0,6167]
ΔGPR-domestic (-1)									-0,3936	[-3,6852]***	-0,2164	[-2,5171]**					-0,1139	[-0,6505]	-0,1851	[-0,4708]
ΔGPR-domestic (-2)																	-0,0398	[-0,2372]	0,7060	[1,6501]
ΔGPR-domestic (-3)																	0,1045	[0,5472]	0,2868	[0,8156]
ΔGPR-domestic (-4)																	-0,0539	[-0,2580]	0,0637	[0,2146]
ΔGPR-US	-1,8516	[-0,7174]	4,0188	[2,2337]**	-5,6546	[-0,9778]	5,6674	[0,8085]	-0,0094	[-0,0447]	-0,1337	[-0,9043]	0,0356	[0,2822]	-0,1944	[-0,8955]	-8,0447	[-1,8200]*	-6,9659	[-1,3432]
ΔGPR-US (-1)	-3,1387	[-1,2282]	0,9590	[0,5735]	-1,3152	[-0,2178]	12,7661	[1,8253]*	0,4220	[1,5188]	0,2009	[0,9430]	-0,0177	[-0,2039]	-0,2674	[-0,9291]	-4,6220	[-0,8319]	-4,8543	[-0,9553]
ΔGPR-US (-2)					-3,7862	[-0,4625]	12,3015	[1,1143]	0,0426	[0,1745]	-0,2309	[-1,7334]*								
ΔGPR-US (-3)					-2,2376	[-0,2456]	19,1017	[1,2895]												
ΔGPR-US (-4)					-2,1123	[-0,2088]	9,8767	[0,7113]												
ΔEPU-domestic					2,8146	[1,7144]*	4,2164	[1,6902]*												
ΔEPU-USA	-1,3678	[-0,9764]	-1,0676	[-0,7391]					-0,1252	[-0,8336]	0,0949	[0,8203]	-0,0756	[-1,6814]*	0,0657	[0,5852]				
ΔEPU-USA (-1)	4,2950	[2,1444]**	4,5838	[2,7467]***	-1,3152	[-0,2178]	12,7661	[1,8253]*	0,1164	[0,8384]	0,0874	[0,8449]	-0,0362	[-0,3839]	-0,2326	[-0,7427]				
ΔEPU-USA (-2)	1,3871	[0,8195]	1,2405	[0,8843]																
ΔEPU-USA (-3)	-3,1540	[-1,8105]*	-3,1041	[-1,9288]*																
ΔEconomy Openess	-0,5424	[-2,0434]**	-0,2440	[-1,2611]	0,4920	[0,9118]	-0,8482	[-0,9990]									-0,2495	[-2,7975]***		
ΔEconomy Openess (-1)	0,0487	[0,1763]	0,0603	[0,2788]	0,1879	[0,3643]	-0,4647	[-0,8343]									-0,2168	[-1,9879]	-0,5583	[-1,9484]*
ΔEconomy Openess (-2)	0,0734	[0,3017]	0,1101	[0,5143]	0,1810	[0,3517]	-0,8008	[-1,2329]									-0,1611	[-1,0840]	0,1450	[1,0387]
ΔEconomy Openess (-3)																	-0,0833	[-0,6685]	0,6838	[2,7088]***
ΔEconomy Openess (-4)																	-0,1102	[-0,7954]	0,1356	[0,5262]
ΔForeign Reserve					-80,9646	[-1,3100]	-18,7683	[-0,2505]	-9,1070	[-3,2289]***	-0,3290	[-0,3290]								
ΔForeign Reserves (-1)					0,0942	[0,0012]	6,0927	[0,07305]	-7,2622	[-2,3050]**	1,4201	[0,5867]								
ΔForeign Reserves (-2)					25,4954	[0,3742]	-6,6373	[-0,0853]	-10,3435	[-3,3774]***	-2,5237	[-1,0946]								
ΔForeign Reserves (-3)					23,7844	[0,3558]	37,7364	[0,4336]												
ΔForeign Reserves (-4)					-10,9276	[-0,1379]	58,5636	[0,7010]												
ΔStock Market					-53,8012	[-1,9016]*	-1,4686	[-0,0458]												
ΔStock Market (-1)	-10,2110	[-1,0083]	12,7373	[1,2301]	-21,9719	[-0,6846]	8,2934	[0,3700]												
ΔStock Market (-2)	5,4013	[0,5572]	27,7470	[3,4876]***	-31,5238	[-1,4461]	17,2729	[0,6876]												
ΔStock Market(-3)					-34,6370	[-1,1251]	20,4891	[1,1117]												
ΔTrading Volume	-0,9486	[-0,6498]	0,1714	[0,1146]					0,0189	[0,2019]	0,0060	[0,0891]	0,0460	[0,8041]	-0,1603	[-1,6550]	-6,1656	[-2,4763]**	3,1629	[0,7676]
ΔTrading Volume (-1)	2,2975	[1,4390]	3,8500	[2,7256]***					-0,1337	[-1,2730]	-0,2637	[-4,4021]***	0,0271	[0,6358]	0,1633	[1,9056]*	-4,3216	[-2,0224]**	-5,4489	[-0,9791]
ΔTrading Volume(-2)	-2,4503	[-1,9254]*	-1,4342	[-1,2257]									-0,0213	[-0,3736]	0,0364	[0,2646]	-0,7873	[-0,2497]	8,8690	[2,2657]**
Constant													-0,1358	[-8,5099]***	0,2216	[2,8928]***				

Note: ***, **, *represent significance at 1%, 5% and 10% levels. The figures in parentheses are the t-statistics.

For the **Brazilian model**, the oil price's impact on the Real's volatility is significant for the long-term in the top quantile. In the short run, the current geo-political risk of the US's impact on the Real's volatility is positive and significant in the top quantile. The last lag of the US's economic policy uncertainty, last two lags of the stock market index and the last lag of trading volumes all have significant positive impacts for the top quantile. On the other hand, the last lag of the US's economic policy uncertainty and economic openness has significant positive and negative impacts for the bottom quantile. This implies that, when the currency volatility is great, impacts from the US geopolitical risk, US economic policy uncertainty, stock market index and currency trading volumes significantly explain the volatility movement. When the volatility is low, only the impacts from economy openness become substantial. The US economic policy uncertainty has a consistent negative impact on the Real's volatility no matter volatility is high or low.

For the **Russian model**, the domestic geopolitical risk has a significant and positive impact on the Ruble's volatility in the long run in the bottom quantile. In the short run, no factors have a significant impact at 5% level under extreme volatility conditions.

For the **Indian model**, interest rate differentials (negative), gold (positive), and foreign reserves movement (negative) have significant long run impacts consistently for the bottom and top quantiles. Additionally, the US domestic and economic policy uncertainties have positive long-term impacts only for the top quantile. In the short run, the previous currency volatility of four lags, the foreign reserve of the past one, two and three lags have significant impacts for the

bottom quantile of the Rupee's volatility. The currency variance at three lags and the last term of trading volumes has negative impacts for the top quantile. The last term of the Indian geopolitical risk has consistent impacts both for bottom and the top quantiles. Foreign reserves movement at all last three terms have a negative impact for the short-term Rupee's volatility when the volatility is low, but this effect is not significant when the volatility is high. Similarly, the currency's past volatility affects the current volatility, but the movement of variance at the last three lags has an impact when the volatility is great, and past variance at four lags has an impact when the volatility is extremely low.

For the **Chinese model**, there are no long run significant variables, and in the short run, the last term variance change explains the current RMB's volatility negatively for the bottom quantile. For the top quantile, the impacts of two lags variance and the current oil price change become significant. Note that both past variance impacts on current volatility, in the top or bottom quantiles, are negative. This might imply the capability of RMB to adjust to the equilibrium.

For the **South African model**, the oil price and the US geopolitical risks have a long run impact on the Rand's volatility only for the top quantile. In the short run, many impacts exist. One lag and two lags of the previous Rand's volatility, economy openness, current and one lag previous trading volumes all have significant negative impacts in the bottom quantile. Oil price movements have a negative impact when volatility is extremely low, but have a positive impact when volatility is very high. Three lags of previous trading volumes and three lags of economy openness both have positive impacts for the top quantile.

4.8 Co-integration of the five currencies' volatilities

The ARDL F-bounds tests confirmed that long run cointegrations only exist for the Brazilian and South African models. Moreover, the Rand's volatility and the Ruble's volatility have impact on the Brazilian Real's volatilities in the long run,

while in the short run Real, Ruble, and RMB have impacts on Rand's volatility. The impacts of Rand and Real are bidirectional to each other.

For short run, the South African Rand is found to be volatility transmitter to the others, except Russia. The risk of the Rand has adverse impacts on the Indian Rupee, Brazilian Real, and Chinese RMB, but has no impacts on Rubel. On the other hand, South African Rand is also the greatest volatility spillover receiver. All the risks from other currency markets will be transmitted to South African market in the short run. The spillovers between China and Russia in currency markets are bidirectional. The strong interlinks between Chinese RMB and Russian Ruple volatility mirror the increased bilateral trade in energy, timber and fertilizer, and the strengthen economic and financial ties, with Russia is holding great amount of RMB in its reserves. The short run spillover effects directions across BRICS countries are shown in **Figure 4.7**.

Finally, the Chinese RMB's risk not only has significant long run and short run effects on the Rand's volatility, but also has the greatest magnitude and a positive sign on the Rand's variance. It demonstrates that, the ZAR/USD receives the greatest volatility spillover from the Chinese currency market.

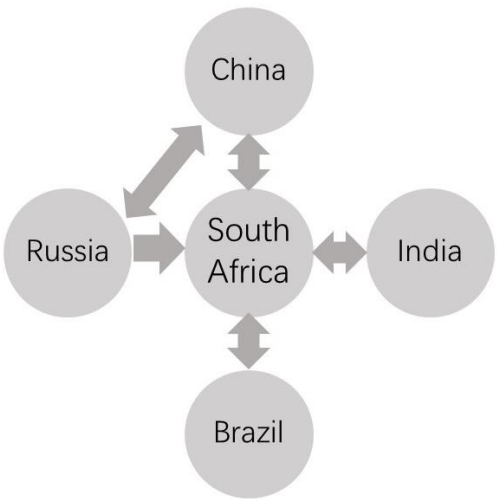

Figure 4.7：Short-run volatility spillover across the BRICS countries

Table 4.7: Cointegration relationship of the five currencies volatility by ARDL Model

	Brazil		Russia		India		China		South Africa	
Long Run Cointegration Estimation Result:										
VAR_B(-1)									0,5750	[3,7261]***
VAR_C	-1,9501	[-1,504]								
VAR_C(-1)									3,6063	[2,7163]***
VAR_I	-0,0807	[-0,2642]								
VAR_I(-1)									0,2762	[0,8696]
VAR_R(-1)	0,0852	[3,8142]***							-0,0565	[-2,1833]**
VAR_Z(-1)	0,4585	[3,4769]***								
Constant	15,6689	[5,1064]***							-6,2855	[-1,4887]
Error Correction Term										
ECT(-1)	-0,6216	[-8,2162]***	-0,2514	[-4,9522]***	-0,0692	[-3,6514]***	-0,0452	[-3,2976]***	-0,4901	[-6,5200]***
ARDL Short Run Estimation Result:										
ΔVAR_B									0,2970	[5,4911]***
ΔVAR_B(-1)									-0,1030	[-1,7053]*
ΔVAR_C			17,3430	[1,9465]*					5,7988	[2,9741]***
ΔVAR_C(-1)			18,4394	[2,1004]**					-3,7395	[-1,8470]*
ΔVAR_C(-2)			17,2319	[1,9549]*					-4,0771	[-2,0194]**
ΔVAR_I									1,3269	[2,9597]***
ΔVAR_R	0,0105	[0,4608]					0,0012	[1,6028]	-0,0052	[-0,2890]
ΔVAR_R(-1)			0,1491	[1,8199]*			-0,0010	[-1,3379]	0,0477	[2,5384]**
ΔVAR_R(-2)			0,1532	[1,8044]*			-0,0022	[-2,8313]***		
ΔVAR_Z	0,5598	[6,8114]***			0,0428	[3,7084]***	0,0110	[3,8303]***		
ΔVAR_Z(-1)					-0,0228	[-1,8021]*			0,0798	[0,9280]
ΔVAR_Z(-2)					-0,0287	[-2,2891]**			0,1668	[2,3418]**
ΔVAR_Z(-3)					0,0329	[2,7289]***				
R Squared	**0,4549**		**0,1795**		**0,2453**		**0,1557**		**0,4898**	
F Bounds Test	**10,8434**	**(cointegration)**	**3,9349**	**(non-conclusive)**	**2,1386**	**(no cointegration)**	**1,7453**	**(no cointegration)**	**6,8082**	**(cointegration)**
F statistic	**57,5938*** **		**5,8638*** **		**10,8089*** **		**6,2244*** **		**12,2880*** **	
Durbin Watson Statistic	**1,9550**		**1,9770**		**1,8961**		**2,1543**		**1,9958**	

Note: ***, **, * represent significance at 1%, 5% and 10% levels. The figures in parentheses are the t-statistics.

4.9 Discussion of the findings

The main findings of the research are summarised as follows:

Commodity price, interest differentials, geopolitical risk and economic policy uncertainty have **significant impacts** on BRICS nations' currency volatility; they are the risk sources of the BRICS currencies in the long term and in the short term. However, the impacts among the countries are **heterogenous**. In the long run, oil prices are the determinants of the RMB's volatility, foreign reserves affect the Brazilian Real and the Indian Rupee's volatility, home geopolitical risks explain RMB and the Rupee's fluctuation, and interest rate differentials explain RMB volatility. The study on BRICS currency markets heterogeneity is rare, but the research of Ahmad et al. (2018) has confirmed the heterogeneity of the BRICS stock markets.

The **USA** monetary policy, geopolitical risk and economic policy uncertainty have significant spillover effects on BRICS' currency volatility, while the impacts on different countries are **heterogenous**, indicating by different coefficients signs of US geopolitical risk, and by the significance of US EPU impact only applies for India and Brazil. The US geopolitical risk only affects the Rand's volatility in the long term. In the short term, the US geopolitical risk affects all the currencies significantly except for Brazilian Real. Such an impact on the Russian Ruble is persistent including four lags. The short-term impacts for BRICS currencies are all negative, except for the Indian Rupee which is positive. The findings of heterogeneousness have implications for the investors in forming hedging and portfolio diversification strategy. Moreover, it also has important implication for policy makers in terms of optimal currency area proposal in BRICS.

The impacts of **interest rate differentials** are significant for Chinese RMB in long term, and significant for Russian Ruble in short term. The study of Ray

(2020) argues the other three countries have the inflation-targeting monetary policy, while China and Russia are taking the multiple indicators approach, for the purpose of maintain the currency value stability. The difference of the monetary policy might explain the variations in correlation of interest rate and exchange rate across BRICS nations. The study also found the declining impact of interest rate differentials on RMB for the last 15 months and the insignificance of such a impact in short run. The finding conflicts with study of Long et al. (2022), who claims the impacts of Sino-US interest rate differentials on the RMB's exchange rate was weaken after the 2008 financial crisis, but intensified during Covid-19 pandemic. The sample period for the work of Long et al. (2022) was July 2005 to July 2021. While the study is focus on 15 months period from June 2022 to September 2023 for shock evolution analysis, and short-term period is defined by current to previous five months. The above variations in sample selection of the two studies could explain the opposite conclusions.

South Africa is a **gold** exporter. However, the oil price fluctuation has impacted on the South African Rand's volatility, while the effect of the gold on the Rand is not significant. This finding is aligned with the recent study of Chen et al. (2022). It can be explained by South Africa's decrease in world share of gold production. South African gold production is in declining in trend, from a peak of 1,000 ton in 1970's to 92,6 ton in 2023, accounting for only 4% of world output dropping from 75% in 1968 (Hirsch, 1968). The gold price's impact is only significant in India, both in the long term and in the short term.

The world's biggest and fasted-growth energy producer and consumers are all members of BRICS countries (Qabhobho, 2023). In general, the **oil price** affect BRICS' currency volatility of both the oil producers (Russia and Brazil) and oil consumers (China, India and South Africa). The impacts on the long run and at the current term are positive for the oil consumers, and negative for the oil producers, indicating by the signs of coefficients. The study of Villarreal-

Samaniego (2021) also shows the similar result for oil exporting countries. Our findings are well explained by the oil price and exchange transmission models of internation portfolio allocation of Krugman (1983) and wealth approach of Golub (1983).

The **opposite sign** at current and lagged term exists for most BRICS nations. Russian Rubel's volatility is negatively affected by current interest differentials and positively affected by three-months lagged interest differentials. The Indian currency volatility has negatively associated with current USA geopolitical risk and positively associated with its lag terms. The oil price is negatively related to currency volatility at contemporaneous term and positively to lagged term both in China and in South Africa. Saha and Chakrabarti (2019) also find that the opposite signs of the contemporaneous and lagged coefficients of oil prices. The finding has important implication for investors since it indicates the extra risks in BRICS' currency market.

The Chinese RMB's volatility showed a clear **shock evolution**. According to the 15-month analysis in the research, the increasing impacts of the US geopolitical risk, US economic policy uncertainty, Chinese economic policy uncertainty, and the oil price exposure, as well as the decreasing impacts from interest rate differentials risk and local geopolitical risk, have determined RMB's volatility. Study on this topic is rare, but Wang et al. (2023) and Long et al. (2022) report that an increase in US monetary policy uncertainty worsens RMB's exchange rate volatility, and can have a significant impact on RMB's volatility through the intermediate transmission of China's direct investment flows and portfolio investment flows. The study considers that the increasing importance of geopolitical risk, policy uncertainty and oil price in determining RMB's volatility, is the reflection of the rising US-China political conflictions during and post COVID-19 pandemic, and is the result of increasing deglobalization in supply chain, trade, investment and even technology under the US sanctions,

especially after the Russian-Ukraine war. Nevertheless, China is the most important market for many investors looking for high growth and future potentials. Investors need to understand the new changes in China to effectively manage the risks, especially the risk of Chinese currency. Given the rising Chinese economy is regarded as the engine of growth for BRICS nations, such evolutionary changes in Chinese market should raise an alert for the policy makers of the other BRICS countries.

The QR indicates that the currencies' responses to the determinants differ in the top and bottom quantiles. When volatility is at an **extremely high level**, the commodity price (Brazil for the long term, South Africa and China for the short term), geopolitical risk of US (Brazil for the short term), economic policy uncertainty of US (Brazil for the short term), domestic geopolitical risk (India for the short term) and economic policy uncertainty (India for the short term) **become significant** to determine currency volatilities, while such effects are insignificant in the bottom quantile. Likewise, the currency volatility becomes responsive and sensitive to stock market change and trading volume dynamics when volatility is high, which are the case for Brazil, India and South Africa. Our QR study suggests the significant effect of oil on currency volatility is only visible in the upper extreme quantiles in China, which is agreed by the findings of Qabhobho (2023).

Long-run cointegrations for Brazilian and South African currency volatility is confirmed. This long run volatility bidirectional spillover between Real and Rand, offers evidence that some degree of integration have been achieved in Brazilian and South African currency market. It might be the similarity in South African and Brazilian economics, institutional structures, or shocks transmission through the markets. Additionally, the ZAR/USD receives the greatest volatility spillover from the Chinese currency market in the long run. Compared to the work of Raputsoane (2008) who discovers no significant volatility spillover from

Chinese RMB to the Rand, our finding suggests the new change results from rising trade, financial and monetary ties between countries after the formation of BRICS, and also has implication in formulating the optimal monetary policy. Finally, the finding of South African currency has the greatest links with other currency markets in BRICS, agrees with the finding of Mittal et al. (2019). For the international investors, the above findings of connectedness suggest the risk factors, as well as imply the hedging opportunities between the low correlated currencies.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The research investigated the five individual BRICS countries' currency volatility determinants, and examined the connectedness of their volatilities. The result indicated that commodity prices, interest rate differentials with the USA, domestic and US geopolitical risks, and domestic and US economic policy uncertainties have impacts, with magnitudes and signs differing on BRICS' currencies' volatility in the long and in the short run. In addition, the impacts of oil price, geopolitical risk and economic policy uncertainty on currency volatility are usually significant at the 90% quantile, in other words, under very high volatility conditions. Moreover, the findings imply that the impacts of commodity price, US monetary shocks, US geopolitical risks and US economic policy uncertainty are asymmetric on the BRICS nations' currency volatility. Given the magnitudes of volatility are so different amongst BRICS countries, the findings suggest that a currency union in BRICS under the current conditions might not be optimal, however, an anchor currency, such as RMB, could be an alternative option. Nevertheless, investors might utilise this heterogeneity and mitigate risks by diversification and effective hedging.

The other finding is regarding the connectedness of the BRICS currency volatility. Brazilian and South African currency markets are cointegrated, since the Real and the Rand affect each other on both the long run and the short run. The Chinese currency market risks have long run and short run impacts on the South African Rand, with great magnitude. The volatility spillover of Russian Ruble and RMB's risk are bidirectional. The connectedness of the currency volatility can be explained by the increase of trade intensity, internal capital flows and financial co-operations amongst the BRICS nations. The findings provide meaningful information for policy makers, suggesting the importance of consideration of global markets when creating the macroeconomics policies. The findings have another implication for BRICS members, as sub-groups in

BRICS nations may benefit from a unified currency, and bilateral currency agreement in trading can be alternative options in the current context. Additionally, the weak connectedness, for example between India and Brazil, could offer the investors an opportunity for effective hedging.

The research used a nominal exchange rate with the USD to derive dependent variables, with the assumption that the USA is the dominant trade partner for most BRICS countries. It will be beneficial and interesting to broaden the study by examining the real exchange rates' behaviour and compare the results from the two rates. Moreover, the study on the currency volatility is based on symmetric ARDL analysis. Further study could explore the NARDL model which could address the asymmetric and nonlinear behaviour of currency movement more accurately.

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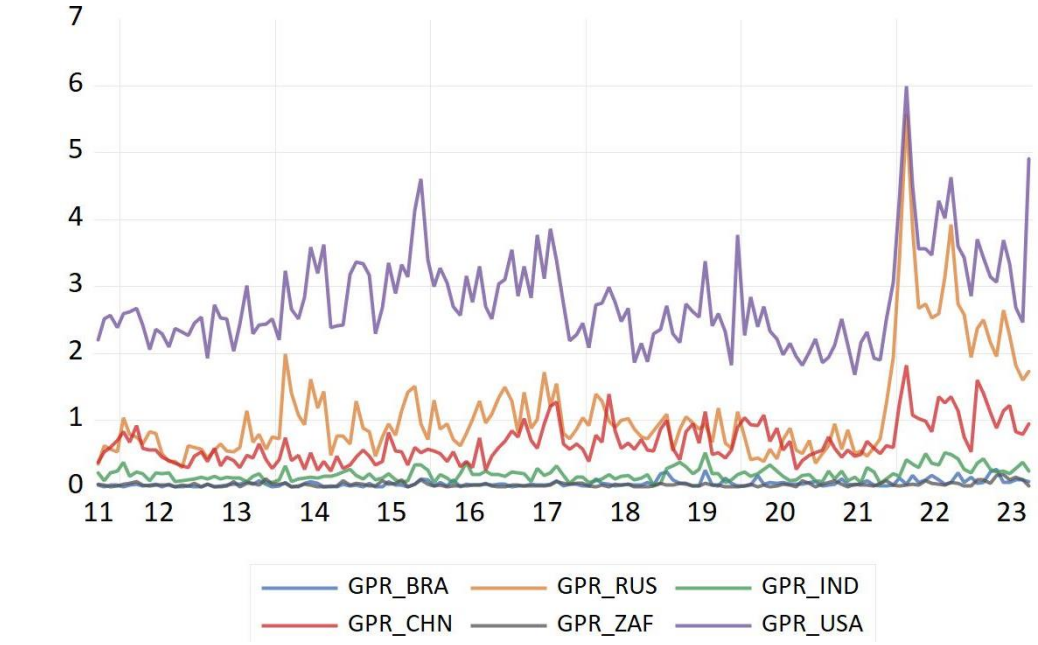
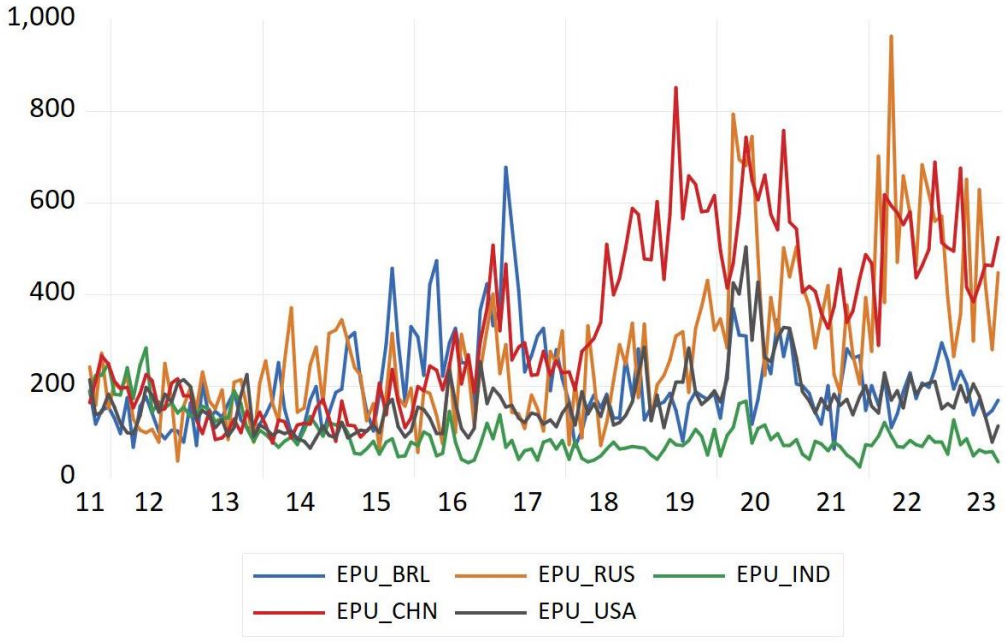
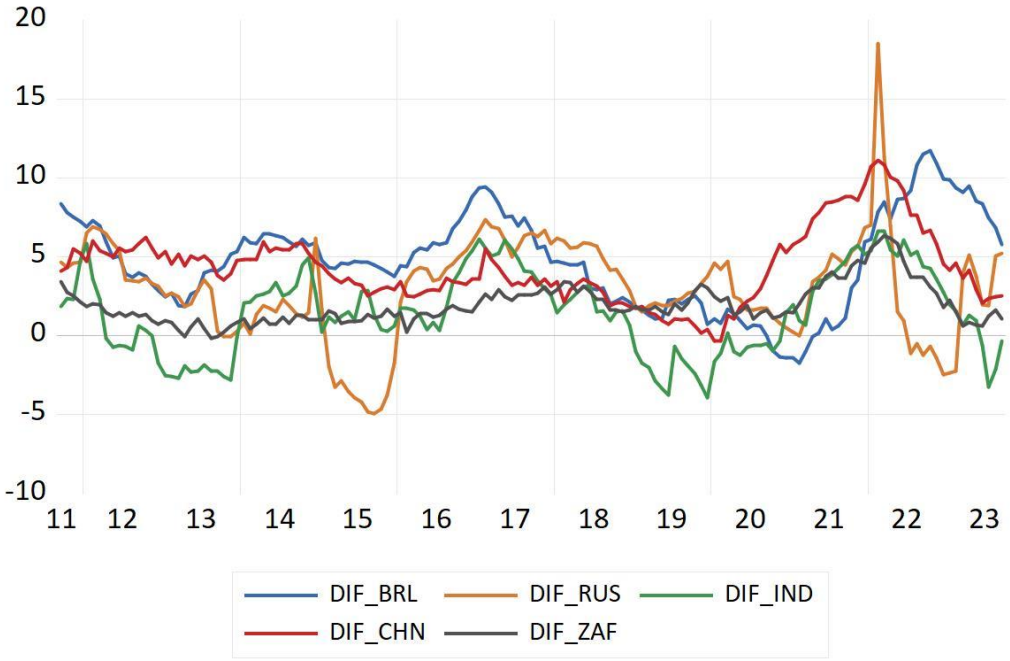
APPENDIX A: Comparison of raw GPR and EPU data of the BRICS countries and USA

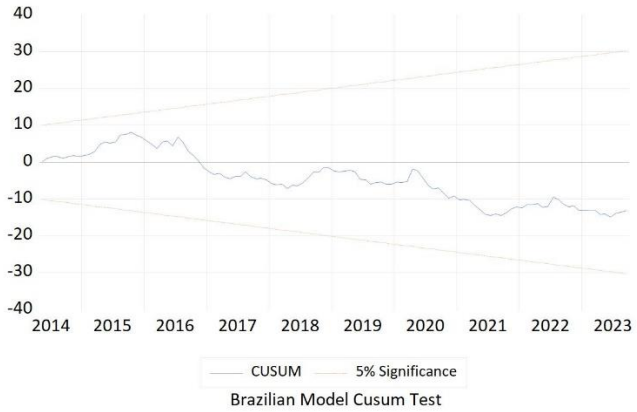




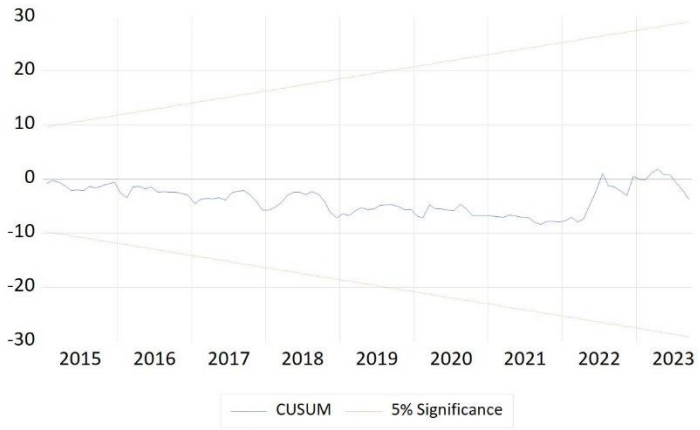
APPENDIX B: Comparison of BRICS countries' Interest Rate Differentials With US



APPENDIX C: CUSUM Recursive Tests for ARDL Models



Brazilian Model Cusum Test



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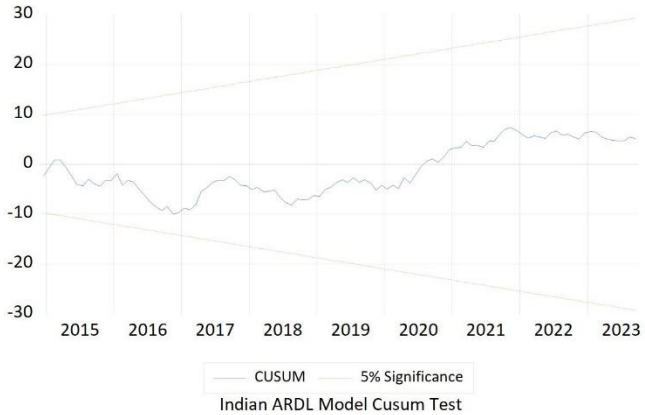
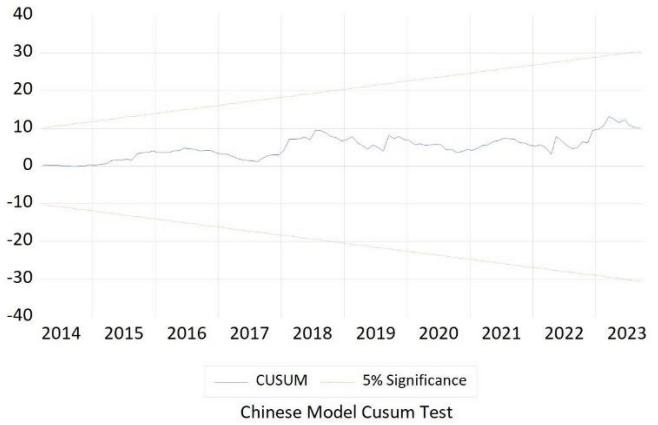
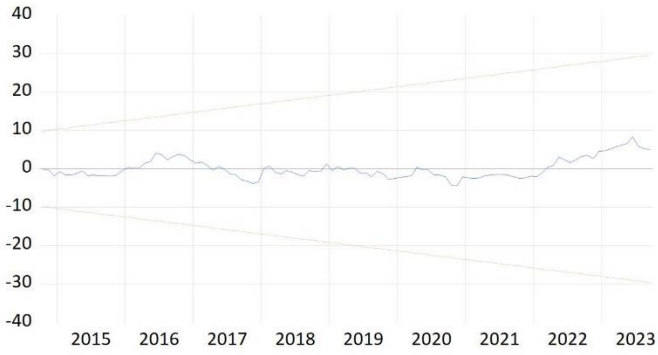


Indian ARDL Model Cusum Test

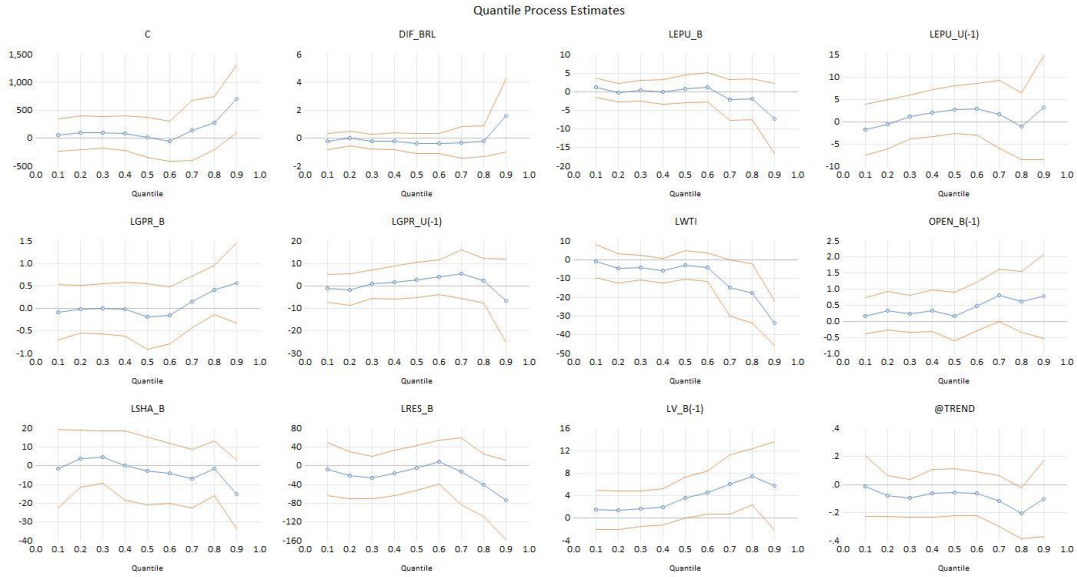


Chinese Model Cusum Test

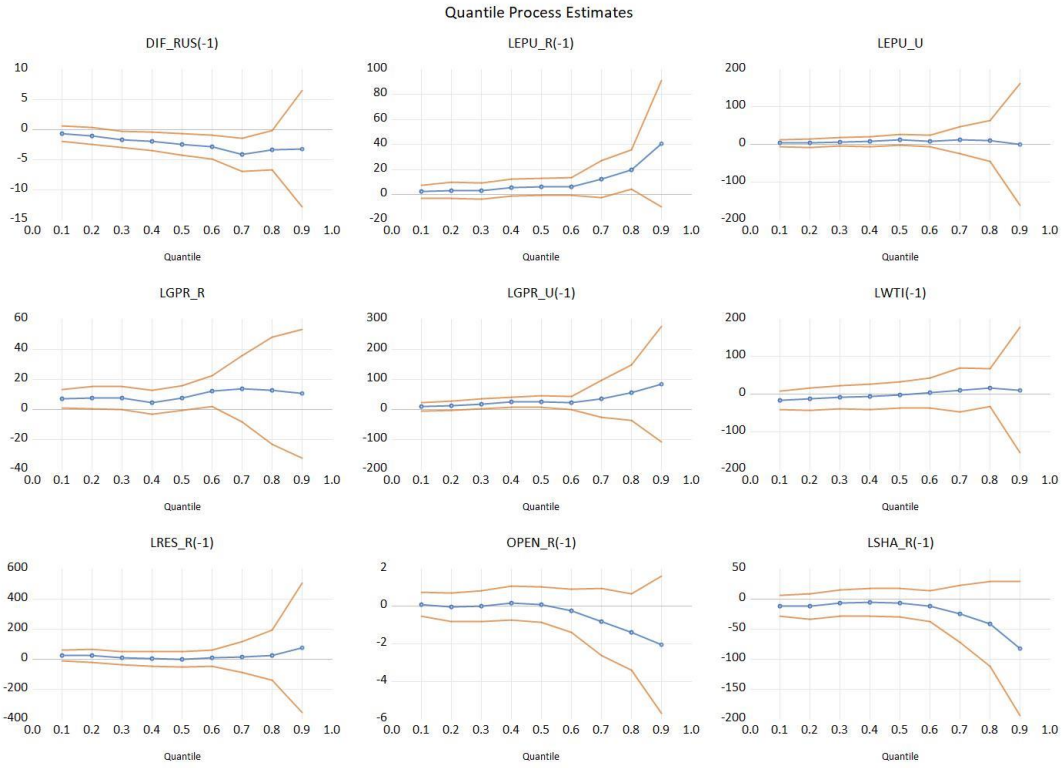


South African Model Cusum Test

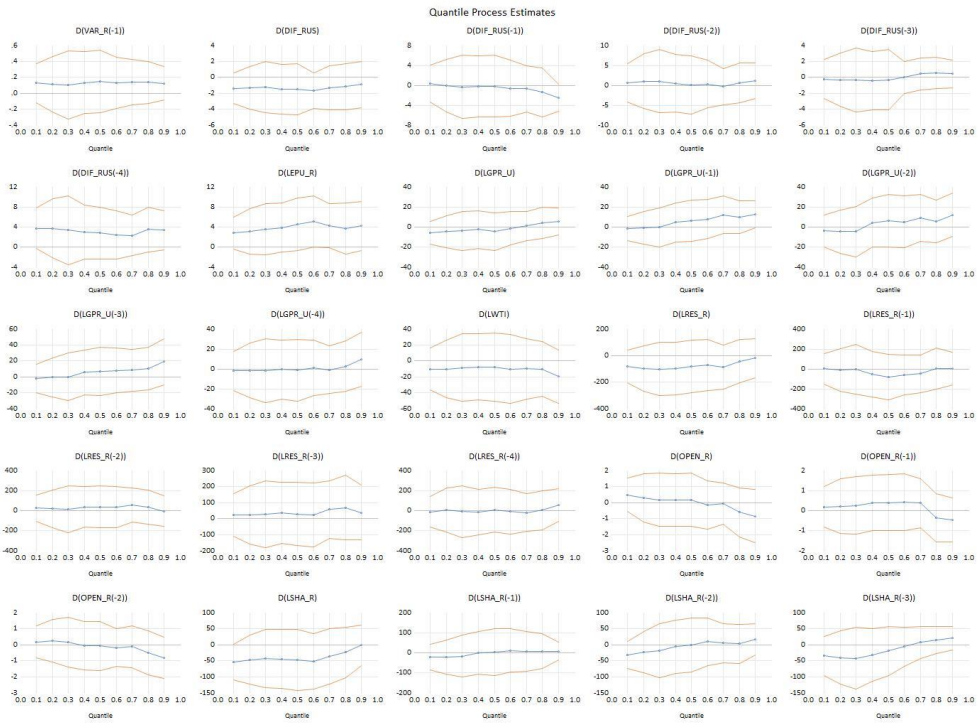
APPENDIX D: Quantile Regression-Long Run and Short Run



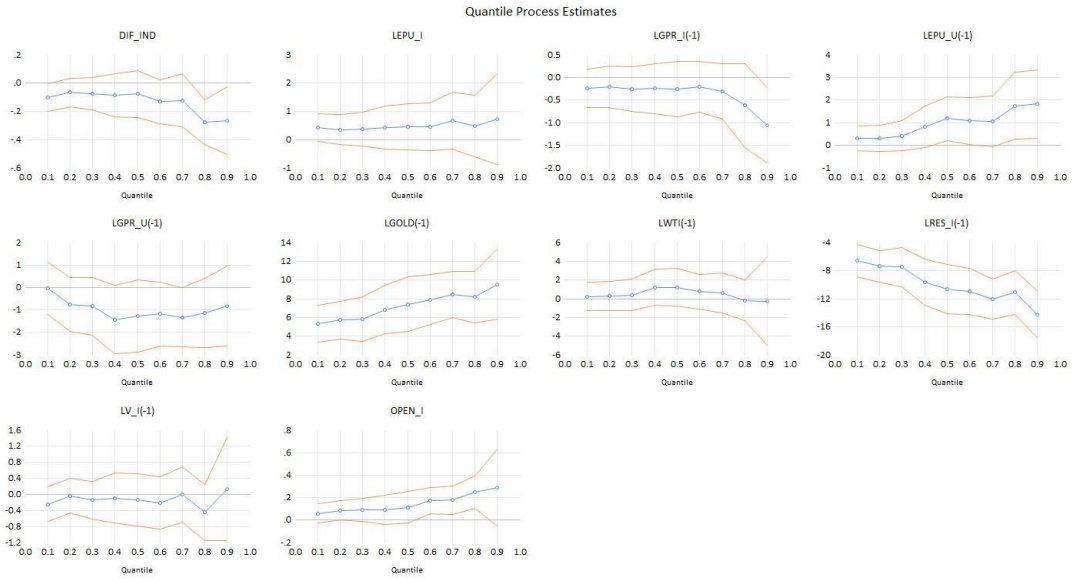
Quantile Regression for Brazilian Real (Long Run)



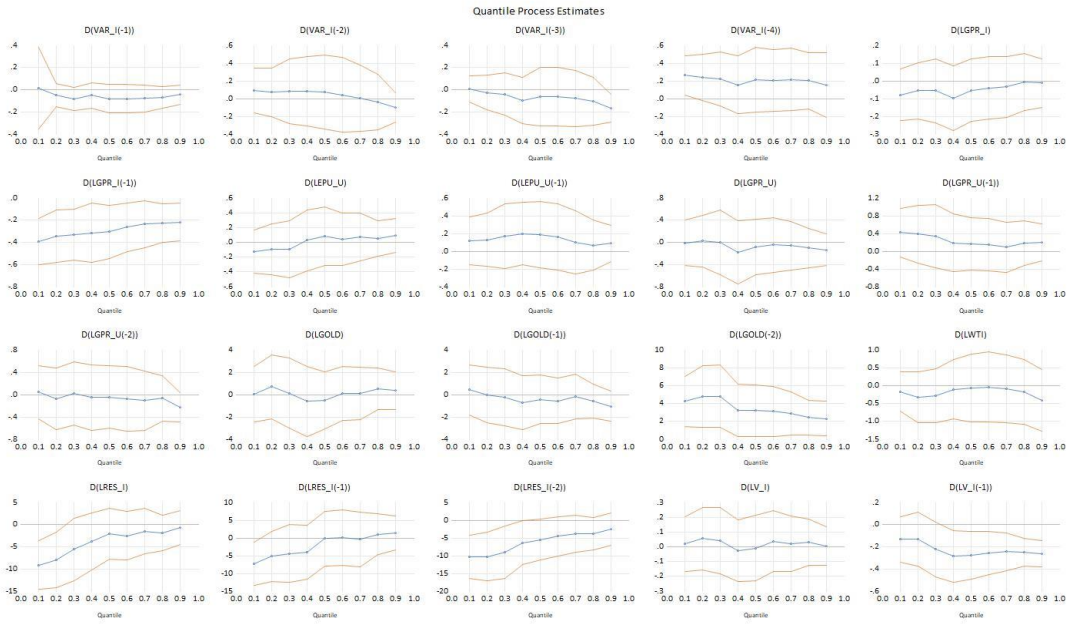
Quantile regression for Russian Ruble (short run)



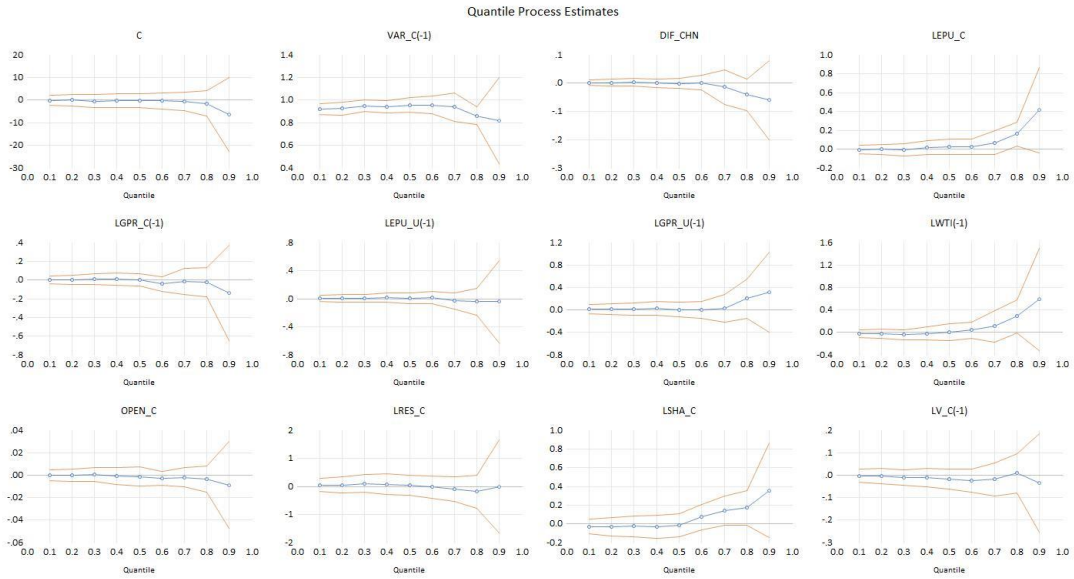
Quantile regression for Russian Ruble (short run)



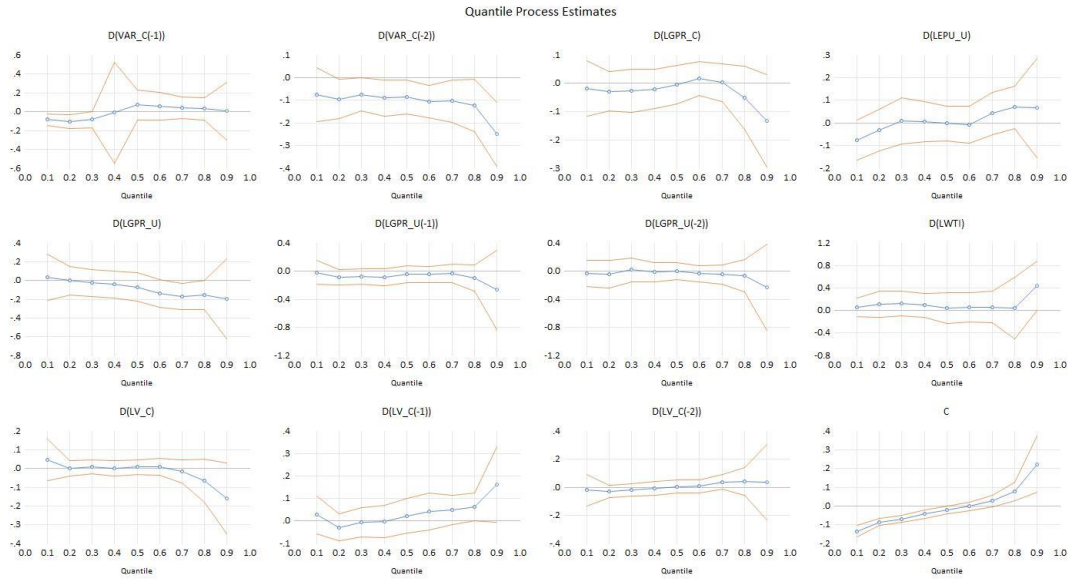
Quantile regression for Indian Rupee (long run)



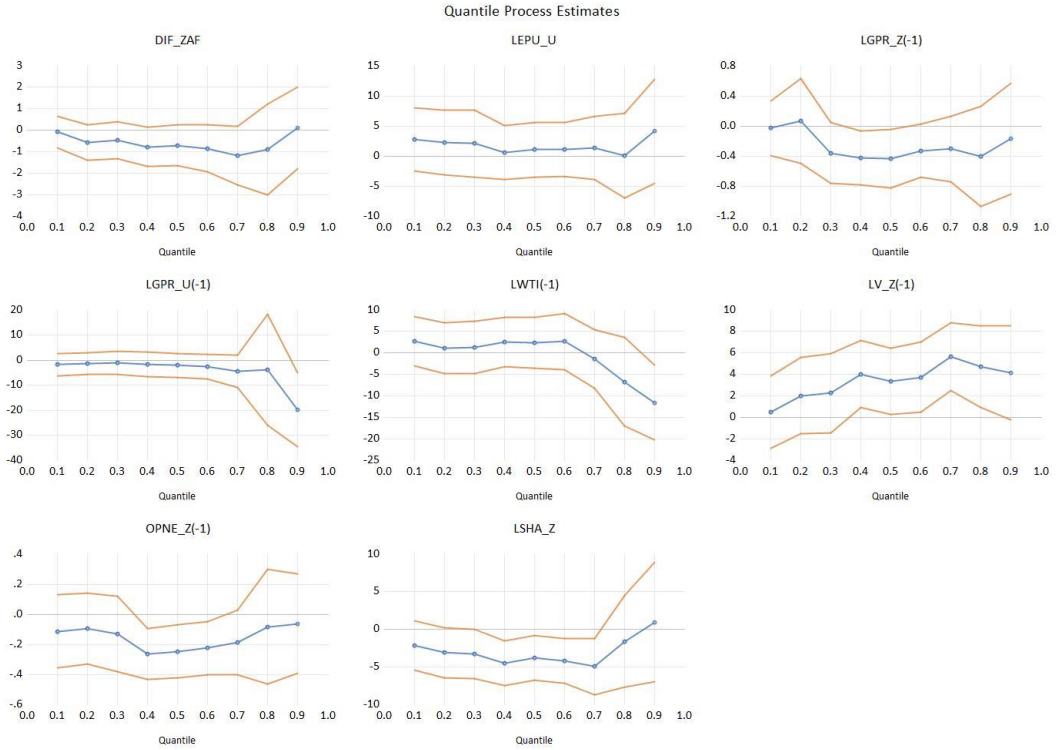
Quantile regression for Indian Rupee (short run)



Quantile regression for Chinese RMB (long run)



Quantile regression for Chinese RMB (short run)



Quantile regression for South African Rand (long run)

Quantile regression for South African Rand (short run)

APPENDIX E : Ethics Clearance

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School Ethics Committee

2023/11/13

Ethics clearance number: **WWBS/FI2397580/906**

RE: Mrs Heng Luo

To whom it may concern

Mrs Heng Luo (2397580) is currently registered as a MM in Finance and Investment student at the Wits Business School, University of the Witwatersrand, Johannesburg.

This letter is to confirm that, at the time of writing, Heng Luo does not need ethical clearance for the study entitled:

Currency volatilities of BRICS countries: the impact of commodity prices, interest rates and geopolitical risks

This decision has been reached based upon a description of the project supplied by Heng Luo to the Wits Business School Ethics Committee, constituted as a subcommittee of the University Human Research Ethics Committee (Non-Medical), which has been evaluated by the subcommittee chair. This decision has then been ratified by the University Human Research Ethics Committee (Non-Medical).

If, however, Heng Luo changes the methods of data collection and analysis for this project, this decision may no longer be valid. If such changes take place, this should be communicated to the Wits Business School Ethics Committee.

Please feel free to contact me or the supervisor should you require any further information.

Yours sincerely,

Dr Pius Oba
☎ +27 11 717 3976
+27 82 733 6587
✉ pius.oba@wits.ac.za

Supervisor:
Dr Odei-Mensah
011-7173997
✉ jones.odei-mensah@wits.ac.za

Declaration by Researcher

One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethics Committee.

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

Signature

18 Nov 2023

Date: