A Comparative Analysis of Currency Volatility among BRICS Countries

Mulatu F. Zerihun[†],Marthinus C. Breitenbach[*], Bernard Njindan Iyke[‡]

Abstract

In recent years, exchange rates of the BRICS countries have all experienced periods of high volatility. Thus far, no study has simultaneously compared the volatility of the BRICS currencies and analyzed the dependence and causal structure of relative volatility of these peer currencies. We addressed this issue by using monthly data from January 1995 to January 2017. We find that:(i) Brazil, India and China are more competitive than South Africa, on average, while South Africa, in turn, is only more competitive than Russia;(ii) the rand has been more volatile than the Brazilian real and the Russian ruble, but less volatile than the Chinese renminbi and the Indian rupee; (iii) there are inter-currency volatility correlations among the real, renminbi, ruble, and rand;(iv) the renminbi return volatility causes return volatility in the real, ruble, and rand.

Keywords: Exchange rate volatility; South Africa; BRICS countries; GARCH.

JEL Classification: E32; F31; F33.

Acknowledgments:
This paper was presented at World Finance Conference held at St. John's University in New York from July 29-31; 2016.We would like to acknowledge the valuable comments suggested by the conference participants that improved the current version of the paper.

1. Introduction

According to Chinn (2006), the exchange rate is the key relative price in international finance, as well as in goods and asset markets. However, different variants of the exchange rate and different exchange rate transmission mechanisms make the study of exchange rates complicated.The exchange rate refers to the price of a country's currency expressed in terms of a foreign currency (O'Sullivan and Sheffrin, 2003). Currency fluctuations are a natural outcome of the floating exchange rate system currently pursued by most major economies (Bahmani-Oskooee and Hajilee, 2013).

[†] Corresponding author, Senior Lecturer at the Department of Economics, Faculty of Economics and Finance, Tshwane University of Technology, Private Bag X680, Pretoria 0001, South Africa. Corresponding author: phone: +27 (012) 382 0557 Email: Zerihunmf@tut.ac.za

[*] Associate Professor of Economics, Department of Economics, University of Pretoria, Pretoria 0002, South Africa, phone: +27 (012) 842 3437, Email: martin.breitenbach@up.ac.za

[‡]Research Fellow, Department of Finance, Deakin University, 221 Burwood Highway, Melbourne, Victoria 3125, Australia.

The exchange rate of one country relative to its major trade partners is influenced by numerous fundamental and technical factors (Montiel, 1997). The predominant factors identified in the literature are, among others, terms of trade (Goldfajn and Valdes, 1999), government spending (De Gregorio *et al.*, 1994; MacDonald and Ricci, 2003), world commodity prices (Chen and Rogoff, 2002), trade openness (Montiel, 1997; MacDonald and Ricci, 2003), and net foreign assets (Lane and Milesti-Ferretti, 2000).These factors are mostly explained by various economic theories of the exchange rate. For example, from the optimum currency area literature, the key long-term determinants of the exchange rate are economic size and trade openness (Mundell, 1961; McKinnon, 1963). In contrast, the exchange misalignments literature emphasizes the relevance of relative productivity (Balassa, 1964; Samuelson, 1964, Bhagwati, 1984), while the fundamental equilibrium theory identifies the need for internal and external balance in the economy (Berger *et al.*, 2000; Hausmann *et al.*, 2001).

Generally, some exchange rates are more susceptible to changes in these determinants than others. As a result, currencies are commonly termed as weak (highly depreciated or devalued) or strong (highly appreciated or revalued) depending on their susceptibility to these factors. The public seems to prefer a strong domestic currency. It must be noted, however, that currency depreciation and appreciation have advantages and disadvantages. For instance, a strong currency can significantly lower economic activities in a given country by making industries uncompetitive (see Rodrik, 2008). In a real sense, what is good for both consumers and producers is currency stability. Thus, studies on exchange rates recommend a stable and competitive exchange rate, and sound macroeconomic fundamentals as tools to enhance a country's international competitiveness and greater penetration of its exports to international markets (Rodrik, 2008).

South Africa is one of many small open economies whose currency is largely exposed to changes to domestic fundamentals and global market events. According to the IMF (2013), South Africa's *de jure* exchange rate arrangement is free floating, and the *de facto* arrangement is floating. Such a currency arrangement has exposed the country's exchange rate to changing external conditions, which has adversely affected the country's overall economic performance (see Cassim *et al.*, 2004; Edwards, 2008; Iyke, 2017). In fact, the country's currency, the rand, has experienced prolonged periods of depreciation in recent times (Iyke, 2017).The depreciating South African rand could be attributed to a range of domestic and global factors. Among these are South Africa's worsening current account deficit, economic slowdown, an energy crisis, recent inflation due to drought in the country, and escalating global risk aversion as investors flee to "*safe havens*" away from the perceived risks of emerging economies like South Africa.

South Africa, together with Brazil, Russia, India, and China, forms the association of five major emerging national economies commonly referred as the BRICS economies (O'Neill, 2001; Carmody, 2013). Like South Africa, currencies of the remaining BRICS countries have generally exhibited a weakening trend starting in 2008, with a sharp depreciation of currencies ensuing as the global financial and economic crises intensified (IDC, 2013). In response, there is a growing body of literature exploring the sources of the weakening currencies of these countries, their volatilities, and the economic consequences (see example, Singh, 2002; Takaendesa, Tsheole, and Aziakpono, 2006; Bahmani-Oskooee, Harvey, and Hegerty, 2013; Nishimura and Hirayama, 2013; Chkili and Nguyen, 2014). For instance, Das and Roy (2016) find significant return co-movement and volatility spillover between the foreign exchange markets with emerging markets

(India, China, Brazil and South Africa) as the net receiver of volatility and developed markets (Euro area, Japan, Australia, and Switzerland) as the net transmitter of volatility. We add to these studies by: (i) comparing the volatility of the BRICS currencies, and (ii) analyzing the causal structure of the BRICS currencies. Our analysis has the advantage that it exclusively focuses on detailing the extent of the volatility of a BRICS currency vis-à-vis its peer currencies, as well as shedding light on which peer currency matters for exchange rate policy in a particular BRICS country. A unique contribution of our study is that unlike prior studies, we estimate both nominal and real exchange rate volatility. This allows us to compare the nominal and real performance of peer currencies. The merit of this approach is that beyond understanding whether a currency is currently weakening or improving against its peers, we are also able to assess the relative international competitiveness of BRICS peers.

In order achieve our objectives, we employ monthly exchange rate data spanning the period January 1995 to January 2017. Using a GARCH specification, Pearson correlation technique, and a bivariate Granger Causality model, we document the findings. In light of these findings we identify a number of policy implications. The remaining sections of the paper are organized as follows. In the next section, we present a brief literature review on the importance and the volatility of the exchange rate. Section 3 describes the data and the model specifications. Section 4 presents the results. Section 5 concludes the paper.

2. Literature review

There have been many studies carried out to understand the dynamics of currency fluctuations in the fields of international economics and finance. The following are recent seminal studies[§] on exchange rate volatility, which have been at the center of a large body of exchange rate research in recent years. The most important papers in this field, among others, are Della Corte, Sarno and Tsiakas (2009, 2011), Menkhoff, Sarno, Schmeling and Schrimpf (2012), and Cenedese, Sarno and Tsiakas (2014). Della Corte, Sarno and Tsiakas (2009) using Bayesian econometric methods of estimation assess the economic value of exchange rate predictability and arrive at important findings. Later on the same authors, Della Corte, Sarno and Tsiakas (2011), use the theoretical context of the empirical rejection of the Uncovered Interest Parity (UIP) condition, commonly referred to as the "carry trade", which suggests that the forward exchange rate is a biased predictor of the future spot exchange rate. This study investigates the empirical relation between spot and forward implied volatility in foreign exchange. Using foreign exchange implied volatility market data, the sample focuses on the exchange rates of nine countries[**] relative to the US dollar that begins in January 1996 and ends in September 2009 (3,571 observations). They compute the forward implied volatility that corresponds to the delivery price of a forward contract on future spot implied volatility. Their results provide strong evidence that forward implied volatility is a systematically biased predictor that overestimates movements in future spot implied volatility. Menkhoff, Sarno, Schmeling, and Schrimpf (2012) further extend the "carry trade" to global foreign exchange volatility and

[§] We are grateful and would like to acknowledge one of the anonymous reviewers who recommended these studies to be incorporated in the literature review of this paper.

[**] The Australian dollar (AUD), the Canadian dollar (CAD), the Swiss franc (CHF), the Euro (EUR), the British pound (GBP), the Japanese yen (JPY), the Norwegian kroner (NOK), the New Zealand dollar (NZD), and the Swedish kronor (SEK). Except for the Euro (EUR) that begins in January 1999 (2,804 observations).

find that high interest rate currencies are negatively related to innovations in global foreign exchange volatility, and thus deliver low returns in times of unexpected high volatility. Subsequently, Cenedese, Sarno, and Tsiakas (2014) further investigate the predictability of "carry trade" returns and discover a new currency strategy with highly desirable return and diversification properties, which uses the predictive ability of currency volatility risk premium[††] for currency returns. More recently, Sarno, Tsiakas, and Ulloa (2016) using a similar strategy find that the currency volatility risk premium has substantial predictive power for the cross section of currency returns.

The literature on the exchange rate is vast. Hence, it is impossible to comprehensively survey all the literature in this study. Since our aim is to explore the relative performance of the BRICS currencies, in the next subsections we first briefly review the importance of the exchange rate. Then, because this study follows previous studies on South Africa, we briefly review these studies on exchange rate volatility in the South African context.

2.1. The Importance of the exchange rate

The exchange rate shows the price of a country's currency expressed in terms of a foreign currency (O'Sullivan and Sheffrin, 2003). It is therefore key to international transactions. The choice of exchange rate policy impacts the balance of payments, flows of capital and many other macroeconomic indicators (see e.g., Berger *et al.*, 2000). The movements of the exchange rate indicate a country's competitiveness over time. For this reason, exchange rate policies are designed to make currencies stable and competitive (O'Sullivan and Sheffrin, 2003).

Changes in the exchange rate have significant implications for an economy. Because it influences a country's international competitiveness, changes in the exchange rate affects a country's growth rate (Rodrik, 2008).Various studies have investigated the impact of changes in the exchange rate – misalignments and volatility – on a country's growth (Rapetti, 2006). Eichengreen (2007), for example, find that the real exchange rate (RER) is a relevant policy tool for development in the case of countries like Japan, Hong Kong, Singapore, South Korea, Taiwan, and China. Similarly, Bahmani-Oskooee and Hegerty (2008) and Bahmani-Oskooee and Hajilee (2013) find that exchange rate volatility could have a profound impact on macroeconomic variables in the countries that adapted a flexible exchange rate regime. Vieira *et al.* (2013), using panel data for 82 advanced and emerging countries, find that a more volatile RER has a significant negative effect on growth. Moreover, Arize *et al.* (2003), studying a sample of 10 least developed countries (LDCs) including South Africa, find that exchange rate volatility exerts a significant negative effect on export demand in both the short run and the long run. There are also few studies that document the drivers of exchange rate volatility and its potential consequences among sub Saharan African countries (Musila and Al-zyoud, 2012; Alagidele and Ibrahim, 2017).

In summary the literature shows that while changes in the exchange rate can be beneficial, it may also be detrimental to a country. It appears that misaligned currencies can be exploited by developing countries to grow faster (Eichengreen, 2007; Rodrik, 2008). However, deliberate

[††] Is the difference between expected realized volatility and model-free implied volatility—reflects the costs of insuring against currency volatility fluctuations (see Sarno, Tsiakas, and Ulloa, 2016).

currency misalignment policies may also be associated with excessive exchange rate volatility which is harmful to growth (Bahmani-Oskooee and Hajilee, 2013; Vieira *et al.*, 2013). Therefore, exchange rate policies should be aimed at striking a balance.

2.2. Exchange rate concepts and literature on exchange rate volatility in South Africa

Two basic concepts are used throughout the paper. These are nominal effective exchange rate (NEER) and real effective exchange rate (REER). NEER shows the value of the local currency against a weighted average of foreign currencies. A rising NEER suggests an appreciation of the local currency against the weighted average of foreign currencies. Similarly, REER is NEER divided by a price deflator. A rising REER indicates that exports are becoming expensive and imports cheaper. Thus, a country experiencing rising REER is losing its trade competitiveness.[‡‡]The nominal exchange rate in most developed and emerging market countries is allowed to be determined by market forces (Edwards and Savastano, 1999). The NEER can, therefore, be very volatile as large international payments, receipts and capital flows can give rise to large fluctuations in the supply and demand for currency.

The South Africa's rand, like currencies of most small open economies, is exposed to changes in demand and supply conditions. The rand has been subject to misalignment and volatility over the years (Cassim *et al.*, 2004; Edwards, 2008; Iyke, 2017). A host of factors have been identified as having contributed to this misalignment and volatility. Some of these include the country's worsening current account deficit, economic slowdown, an energy crisis, recent inflation due to drought in the country, and escalating global risk aversion as investors flee to "safe havens" away from the perceived risks of emerging economies (see also Aye *et al.*, 2015).[§§]

A number of studies have investigated the rand performance over the years. For instance, Bhundia and Ricci (2002) and Bhundia and Gottschalk (2003) investigate the sources of exchange rate fluctuations in South Africa and conclude that nominal shocks (changes in money supply and market speculation) were the primary driving forces. MacDonald and Ricci (2004) assess the performance of the South African rand, and conclude that the currency is weak. They identify world commodity prices, trade openness, government spending, and net foreign assets as key drivers of the rand performance.

In a recent paper, Iyke (2017) tests whether the rand has experienced misalignment and conclude that it has been undervalued over the years. By examining the impact of this undervaluation on the various sectors, Iyke (2017) concludes that real undervaluation of the rand exerted a positive influence on agriculture and industry, and a negative impact on services. Other studies investigate how the volatile or misaligned rand influences the South African economy. For instance, Bah and Amusa (2003), using the autoregressive conditional heteroscedastic (ARCH) and general ARCH (GARCH) models, find that rand volatility has a significant and negative effect on exports in both the long and short-run, while the undervalued rand has a positive impact on exporting activity. Similarly, Takaendesa *et al.* (2006), using the exponential generalized autoregressive conditional

[‡‡]See IMF's definition at: http://datahelp.imf.org/knowledgebase/articles/537469-what-is-nominal-effective-exchange-rate-neer and http://datahelp.imf.org/knowledgebase/articles/537472-what-is-real-effective-exchange-rate-reer

[§§] Similar fundamentals are identified by Pétursson (2009) as the sources of exchange rate volatility.

heteroscedasticity (EGARCH) model, find that real exchange rate volatility has a negative effect on real exports.

There also other studies exploring the sources of the weakening currencies of BRICS countries, in general, including Singh (2002), Bahmani-Oskooee *et al.* (2013), Nishimura and Hirayama (2013), and Chkili and Nguyen (2014). However, our study is different from these studies in a number of ways. Firstly, we compare the volatility of the BRICS currencies to their peers. Secondly, we analyze the dependence and causal structure of exchange rate volatility relative to BRICS peers. Our paper has the advantage that it exclusively focuses on detailing the extent of the volatility of BRICS currency vis-à-vis its peer currencies, as well as shedding light on which peer currency matters for exchange rate policy. A unique contribution of our study is that unlike prior studies, we estimate both nominal and real exchange rate volatility. This allows us to compare the nominal and real performance of BRICS currencies relative to their peers. The merit of this approach is that beyond understanding whether a BRICS currency is currently weakening or improving against its peers, we are also able to assess the relative international competitiveness of BRICS countries against its BRICS peers.

3. Data and methodology

3.1. Data

We use monthly data on the nominal and real effective exchange rates (NEER and REER) spanning the period 1995:01 to 2017:01. This data is taken from Bruegel.org with compilation details provided in Darvas (2012). The countries covered are Brazil (BR), Russia (RU), India (IN), China (CN), and South Africa (ZA). For the bilateral exchange rate between South Africa and major currencies, we obtained the data from the South African Reserve Bank (SARB). The NEER and REER offer better exchange rate measures for comparative analysis such as the one carried out here because they show the competitiveness of these countries. NEER measures changes in the value of a currency against a trade-weighted basket of currencies in nominal terms, while the REER measures the changes in real terms (Chinn, 2006). Considering the use of either the REER or the NEER, Rodrik (2008) notes that the NEER and the REER are closely correlated. Generally, both measures tell us the rate at which we can exchange goods of one country with goods of its trading partners (see Chinn, 2006).

3.2. Calculating the currency volatility

To provide a fair assessment of currency volatility, we followed the literature (see Bah and Amusa, 2003; Ndambendia and Al-Hayky, 2011; Vieira *et al.*, 2013, Iyke and Ho, 2018) and use the General Autoregressive Conditional Heteroskedastic (GARCH) model. This measure derives the variance of the log first difference of the effective exchange rate, $r_{it} = \ln(EER_{it}) - \ln(EER_{it-1})$ or returns from the GARCH (1, 1) model. In technical terms, we fit our baseline GARCH model as:

$$r_{it} = \tau_0 + \tau_1 r_{it-1} + \varepsilon_t \quad (1)$$

where r is a first-difference stationary effective exchange rate, τ is the mean value of the effective exchange rate, (or the returns), τ_0 and τ_1 are parameters to be estimated, t is the time period, EER is the information set, that is the raw value of the NEER or REER, ε_t is the error term which has a mean zero and a conditional variance of a known form ${\sigma_t}^2$. The measure of currency volatility is ${\sigma_t}^2$. The form of ${\sigma_t}^2$ is modelled as:

$$\sigma_t^2 = \overline{\omega} + \alpha_1(\varepsilon_{t-1}^2 - \overline{\omega}) + \beta_1(\sigma_{t-1}^2 - \overline{\omega}) \qquad (2)$$

where ω^{-}, α_1, and β_1 are parameters to be estimated. Currency volatility converges to zero if $0 < \ \alpha_1 + \beta_1 < 1$ (see Bollerslev, 1986; Engle and Bollerslev, 1986).The next section reports the summary statistics of these measures of currency volatility.

3.3. Causal relationship – bivariate Granger causality in volatility

We examine the causal relationship between the return volatilities using the Granger Causality framework. The framework is developed by Granger (1969) to examine whether changes in one series causes changes to another. According to this methodology, if the current value of Ycan be predicted using past values of X and considering other information, which include past values of Y itself, then it may be concluded that X Granger-causes Y. The same goes for the value of X. If current values of X can be predicted using past values of Y and of X, it may be concluded that Y Granger-causes X.Consider the following specifications:

$$Y_t = \alpha_0 + \sum_{i=1}^{m} \alpha_i \ Y_{t-1} \ + \sum_{j=1}^{m} \beta_j \ X_{t-j} + u_{1t} \qquad (3)$$

$$X_t = \alpha_0 + \sum_{i=1}^{m} \lambda_i \ X_{t-1} \ + \sum_{j=1}^{m} \delta_j \ Y_{t-j} + u_{2t} \qquad (4)$$

where X and Y are the stationary variables, m is the lag length for X and Y and u_{1t} and u_{2t} are the random error terms (see Gujarati, 2009). The null hypothesis that X does not Granger-cause Y is stated as:

$$H_0 : \ \beta_1 \ = \beta_2 = \ \beta_3 \ = \ ... = \beta_m = 0$$

The alternative hypothesis is represented as follows:

$$H_0 : \ \beta_j \neq 0 \text{ for at least one } j.$$

If the null hypothesis is rejected, it can be concluded that $\beta_j \neq 0$ for at least one j, which means X Granger-causes Y and there is Granger causality.

4. Results and discussions

This section compares the return volatility of the BRICS countries. It also analyses the dependence and causal structure of the volatility of these currencies. But before that, we first show the summary statistics of national currency–US dollar return dynamics. This is followed by the summary statistics and graphical plots of the NEER and REER returns of BRICS countries. We then show the GARCH plots of the NEER and REER currency volatility measures. The section ends by presenting the analysis of the dependency and causal structure of the currency volatilities.

4.1 Dynamics of national currency/US$ of BRICS countries

In this section, by way of descriptive statistics, we compare the performance of BRICS currencies–US dollar returns for the period 1995M01 to 2017M01.The descriptive statistics are shown in Table 1. In order of depreciation, the Russian ruble comes first, followed by the rupee, the renminbi, the rand, and the real (see Panel A). On average, based on the mean estimates of the returns, the South African rand performed better than all the currencies except the ruble. The worst performing currency (in returns) was the renminbi (-0.08%), followed by the rupee (0.29%), and the real (0.5%), while the best performer was the ruble (1.02%) (see Panel B). Using the sample variance of the returns (standard deviation squared) as a measure of volatility (performance), Panel B shows that the rand performed better than the real and the renminbi but worse than the rupee and the ruble.[***] The ruble return is the least volatile return among the exchange rate returns in the BRICS economies, followed by the rupee, rand, renminbi, and the real returns - in that order.

<<Insert Table 1 here>>

4.2. Relative volatility of BRICS currencies

4.2.1. Monthly dynamics of the NEER and REER and their returns (1995:01 to 2017:01)

In this section, we compare the relative NEER and REER developments in BRICS countries vis-à-vis their BRICS counterparts. The NEER measures the change in competitiveness of a country; REER does the same by taking into account the change in costs or prices relative to other countries. A rise in these indicators means a loss of a country's competitiveness. Unlike the bilateral real exchange rate which indexes a currency only to one bilateral partner's price level, the REER does so with a weighted basket of price levels in respect of countries' trade partners. Thus, the REER provides a more accurate measure of relative price developments between a country, on a weighted basis, and its trade partners. The remainder of the paper focuses on NEER and REER returns and their volatilities.

Before proceeding to analysing the volatility plots, we first show the dynamics of the NEER and REER returns by way of summary statistics and graphical plots of the values. Table 2 shows the summary statistics of the NEER and REER in levels and returns for the BRICS economies. We report the Jacque-Bera test, a test for the nested null hypothesis of normality (i.e. skewness is zero and excess kurtosis is zero). If the p-value is greater than any usual significance level (such as $\alpha = 0.10, 0.05$ or 0.01) there is no evidence to reject the null hypothesis of the returns under discussion. For both NEER and REER in levels and returns, the estimates suggest that the variables

[***]Note that this variance is not our main measure of volatility. Ours is the conditional variance derived from the GARCH model in Equations (1) and (2).

are normally distributed. This is important because it gives credibility to the mean and standard deviation estimates, which are influenced by the normality distribution.

Now, let us consider the mean and standard deviation estimates of the NEER levels and returns for these countries (Panels A and C). On average, the NEER of South Africa is higher than that of India, Brazil and China, and lower than that of Russia. Hence, in terms of competitiveness, Brazil, India and China are more competitive than South Africa, on average, during the period 1995M01 to 2017M01. South Africa, in turn, is only more competitive than Russia. This is so because, on average, the rand effective exchange rate has been overvalued when compared with the real, rupee, and the renminbi during period 1995M01 to 2017M01. In terms of returns, the NEER returns of China is the highest, followed by India, Brazil, South Africa, and Russia. In terms of volatility as measured by the variance of the returns (standard deviation squared), the rand effective exchange rate has been less volatile than the ruble and the real. This means that the rand has performed worse than the renminbi, and the rupee over this period.

The mean estimates of the REER are quite consistent with those of the NEER, except that China and Russia interchange positions in the interpretation (see Panel B). That is, Brazil, India and Russia are more competitive than South Africa, on average, while South Africa, in turn, is more competitive than China. In terms of the returns, the best performing is the ruble, followed by the renminbi, rupee, real and rand - in that order. Looking at the standard deviation estimates of the REER returns, the ruble is the most volatile, followed by the real, rand, rupee and renminbi. The rand has performed relatively better than the ruble and the real but worse than the rupee and renminbi over the period. Thus, the two volatility estimates (i.e. NEER and REER return volatility) yield the same conclusion (see Panels C and D). Again, note that the simple variance (or standard deviation) is not our main measure of volatility. Our main measure is the conditional variance of the GARCH model in Equations (1) and (2).

<<Insert Table 2 here>>

Are the summary statistics in Table 2 consistent with the movements in these currencies over the period under study? Figures 1a and 1b show the plots of the NEER and REER for the BRICS countries during the period 1995M01 to 2017M01. Looking at Figure 1a, the rand effective exchange rate has depreciated between 1995 and 2002, appreciated between 2002 and 2005, and depreciated again between 2005 and 2008. The rand experienced depreciation from 2008 to 2011. After this, the rand has been on a downward spiral. The rand trajectory is quite similar to the real and the rupee. The renminbi, by contrast, has experienced mostly an upward trend. The ruble is quite peculiar; it experienced sudden depreciation between 1998 and 1999 and plateaued from 2000 onwards. Using the NEER, it appears that the rand effective exchange rate performed well when compared with BRICS counterpart. Overall, it appears that the rand has been more competitive than the renminbi.

The NEER does not take into account relative prices. Therefore, Figure 1a may be an inaccurate reflection of the performance of these currencies. Now let us consider Figure 1b, which shows the movements of the currencies measured in real weighted terms (REER). Here, the rand path over the years performs better relative to the real and the ruble, especially between 2012 and 2017.

These currencies have all experienced downward spirals over this period. Over the entire period, it appears that the rand has been more competitive than the rupee and the renminbi which have all been appreciating.

<<Insert Figure 1a here>>
<<Insert Figure 1b here>>

Figures 1b and 1c show the returns of the NEER and REER. From these graphs, we see that both the NEER and REER returns have moved within the following min-max bands: real (-23%, 11%), renminbi (-3.5%, 48%), rupee (-6.1%, 6.7%), ruble (-72%, 13%) and rand (-18%, 8.6%). Thus, during the period 1995M01 to 2017M01, the renminbi recorded the highest returns, followed by the ruble, real, rand and rupee. In addition, the ruble recorded the lowest returns, followed by the real, rand, rupee and renminbi. These results are in line with the estimates reported in Table 2.

<<Insert Figure 1c here>>
<<Insert Figure 1d here>>

4.2.2. Volatility of BRICS currencies

The preceding section considers the movements of the currencies in their raw and return forms. In this section, we formally present the volatility estimates. We fit the GARCH(1,1) model in Equations (1) and (2) using the monthly NEER and REER returns data for the 1995M01 to 2017M01. Our measure of currency volatility is the predicted values of σ_t^2 in Equation (2).[†††] The GARCH(1,1) estimates– not reported but available upon request – show that there is convergence.[‡‡‡] Hence, we proceeded to generate the volatility estimates (or the conditional variances). Table 3 show the summary statistics for NEER and REER return volatility estimates, respectively. We are not interested in the volatility of the volatility, so we would disregard the variance of the volatility in our discussion. The ruble is more volatile than the real, rand, rupee, and renminbi. This evidence is contained in the mean estimates of the return volatility in Panels A and B.

<<Insert Table 3 here>>

To gain a deeper understanding of the volatility of the BRICS countries vis-à-vis the other BRICS currencies, we graphed the volatility for the period under study. Figures 2a and 2b show these graphs. Considering the NEER volatility, which is shown in Figure 2a, it appears that the rand has been more volatile than the real and the ruble, but less volatile than the renminbi and the rupee. Barring an extreme spike in 1999, the ruble appears to be the least volatile currency among the BRICS countries, followed by the real, rand, rupee and the renminbi. This evidence is also supported by the REER volatility plots in Figure 2b.

<<Insert Figure 2a here>>
<<Insert Figure 2b here>>

[†††]See Iyke and Ho (2018) for further explanation. [‡‡‡]That is, $\alpha_1 + \beta_1 < 1$ (see also, section 3).

4.2.3. Volatility dependence of BRICS currencies

The comparison of the return volatility of these peer currencies may not provide useful policy insights. Although if a currency is relatively more volatile than its peers it signals the need for policy intervention, it does not necessarily reveal which of these currencies the policymakers should consider in their information set. Understanding the dependence or correlation structure of the currency and peer currencies could enhance the information set available to the policymaker. This section estimates the simple correlation among the return volatility of these currencies. Table 4 shows the results for the NEER and the REER, respectively. Both results (i.e. Panels A and B) indicate the following: Volatility in the real is positively and significantly correlated with volatilities in the renminbi and rand. The implication is that volatility in the real may spill over to the renminbi and rand and vice versa, in the absence of internal shock absorbers. Volatility in the renminbi is positively and significantly correlated with the real, ruble, and rand. Volatility in the ruble has positive spillover effects on the renminbi, and rand. Finally, volatility in the rand affects the real, renminbi, and ruble positively and significantly. The implication that all but rupee return volatilities are interlinked. Volatility in one of these currencies would likely spill over to the other correlated currencies. Figures 2a and 2b in fact show that the volatility in the real bears a resemblance to the rand, and that they are synchronized. Moreover, since the renminbi appears to be always volatile, it means that the rand is likely to be affected. A possible source of this dependence could be attributed to the rise in bilateral transactions between South Africa, China, and Brazil. Figures 3a and 3b shows the extent of the return volatility dependence among these currencies. These graphs are based on five-year window rolling correlations, and thus reflect the fluctuation of the dependence structure over time.[§§§]

<<Insert Table 4 here>>

<<Insert Figure 3a>>
<<Insert Figure 3b>>

4.2.4 Bivariate Granger Causality of BRICS currency returns

In the final part of our empirical analysis, we attempt to see whether the positive and significant correlation estimated between the rand and the real, and the rand and the renminbi are necessarily causal. This is important because, while correlations may signal potential cause and effect relationships, they do not necessarily establish evidence of causality. Causal effects help the policymaker to gauge, for example, the rand's reaction should the real or the renminbi experience volatility. Table 5 shows the estimated bivariate causal relationships among the currencies. We retain the rupee but do not interpret its causal estimates because the correlation coefficients were insignificant in the preceding analysis.

These results show that in the inter-currency volatility association, the most vulnerable currency is the real. This is because volatilities in three currencies (renminbi, ruble, and rand) have a causal impact on the real. The least vulnerable currency is the renminbi because volatility in none of the currencies affects it, while the renminbi exerts a causal impact on the real, ruble, and rand. The

[§§§]We thank the reviewer for this insight.

next in line is the rand which is only causally influenced by the renminbi. The rand return volatility has a significant causal influence on the real and the ruble.

<<Insert Table 5 here>>

5. Conclusion and policy implications

Currencies of the BRICS countries have endured periods of depreciation and volatility in recent times. The IDC (2003) reports that this weakening trend resumed early in 2008, with a sharp depreciation ensuing as the global financial and economic crises intensified. In an attempt to provide suitable answers to these depreciation and volatility episodes, a growing number of studies have emerged. We contribute to these studies by: (i) comparing the volatility of the BRICS currencies, and (ii) analyzing the dependence and causal structure of currency return volatility of the BRICS currencies. Thus far, no study has tackled these two issues simultaneously. Our approach is unique in the sense that beyond exclusively detailing the extent of the volatility of a BRICS currency vis-à-vis its peer currencies, we also establish the peer currencies that matter for exchange rate policy in each relevant BRICS economy. Furthermore, unlike prior studies, we estimate both nominal and real exchange rate volatility, permitting us to compare the nominal and real performance of the rand relative to its peer currencies.

To achieve our objectives, we employ monthly exchange rate data starting from the earliest available date, which is January1995 and terminating in January 2017. Then by using a GARCH(1,1) specification, Pearson correlation, and a bivariate Granger Causality model, we document the following findings. Firstly, Brazil, India and China are more competitive than South Africa, while South Africa, in turn, is only more competitive than Russia. Secondly, the rand has been more volatile than the Brazilian real and the Russian ruble, but less volatile than the Chinese renminbi and the Indian rupee. Except for an extreme spike in 1999, the ruble appears to be the least volatile currency among the BRICS countries, followed by the real, rand, rupee and the renminbi. Thirdly, there are inter-currency volatility correlations among the real, renminbi, ruble, and rand. Fourthly, renminbi returns volatility exerts a causal impact on the real, ruble, and rand returns volatility. The most vulnerable currency is the real.

These findings have a number of implications for policy. In terms of competitiveness, the evidence suggests that four of the currencies (real, rupee, renminbi, and rand - in that order) are quite competitive relative to the ruble. In spite of their overall competitiveness, these currencies are very volatile, and hence its stability should be the focus of exchange rate policy. In light of this, we argue that since the results suggest that the real is causally influenced by the renminbi, ruble, and rand, the policymaker in Brazil would have to consider these currencies when formulating policies to stabilize the real. For the Russian policymaker, his exchange rate reaction function should capture the movements in the renminbi and the rand. The reaction function, in the case of South Africa, should contain the renminbi. This does not necessarily mean that the other currencies should be disregarded. Instead, more weight should be placed on the renminbi. This implication is well-supported by the recent rise in the South Africa–China trade. For instance, the World Integrated Trade Solution WITS has reported that China is now the top trade partner of South

Africa, which means that the renminbi would only gain significant influence on the rand in the future.

Our study is by no means exhaustive. For example, we have not identified the other potential sources of the return volatility of these currencies nor have we considered other factors that may contaminate our bivariate causal analysis. Hence, we encourage future studies to consider these and other issues.

References

Alagidede Paul & Ibrahim, Muazu. (2017). On the Causes and Effects of Exchange Rate Volatility on Economic Growth: Evidence from Ghana, Journal of African Business, 18(2): 169-193.

Arize, A. C., Malindretos, J., & Kasibhatla, K. M. (2003). Does exchange-rate volatility depress export flows: The case of LDCs. International Advances in Economic Research, 9(1), 7-19.

Aye, G. C., Gupta, R., Moyo, P. S., & Pillay, N. (2015). The impact of exchange rate uncertainty on exports in South Africa. Journal of International Commerce, Economics and Policy, 6(01), 1550004.

Bagella, M., Becchetti, L., & Hasan, I. (2006). Real effective exchange rate volatility and growth: A framework to measure advantages of flexibility vs. costs of volatility. Journal of Banking & Finance, 30(4), 1149-1169.

Bah, I., & Amusa, H. A. (2003). Real exchange rate volatility and foreign trade: Evidence from South Africa's exports to the United States. African Finance Journal, 5(2), 1-20.

Bahmani-Oskooee, M., & Hajilee, M. (2013). Exchange rate volatility and its impact on domestic investment. Research in Economics, 67(1), 1-12.

Bahmani-Oskooee, M., Harvey, H., & Hegerty, S. W. (2013). The effects of exchange-rate volatility on commodity trade between the US and Brazil. The North American Journal of Economics and Finance, 25, 70-93.

Bahmani-Oskooee, M., & Hegerty, S. W. (2008). Exchange-rate risk and US–Japan trade: Evidence from industry level data. Journal of the Japanese and International Economies, 22(4), 518-534.

Balassa, B. 1964. “The Purchasing Power Parity Doctrine: A Reappraisal.” Journal of Political Economy 72: 584–96.

Berger, H., J.-E. Sturm, and de Haan, J. 2000. “An Empirical Investigation into Exchange Rate Regime Choice and Exchange Rate Volatility,” CESifo Working Paper No. 263, CESifo Institute, Munich.

Bhagwati, J. N. 1984. "Why Are Services Cheaper in The Poor Countries?" The Economic Journal 94: 279–86.

Bhundia, A. & Gottschalk, J. (2003).Sources of Nominal Exchange Rate Fluctuations in South Africa. IMF Working Paper No.WP33/252. Geneva.

Bhundia, A & Ricci, L.A. (2002). The Rand Crises of 1998 and 2001: What have we learned. IMF Working Paper. Geneva.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. Journal of econometrics, 31(3), 307-327.

Carmody, P. (2013). The Rise of BRICS in Africa: The Geopolitics of South-South Relations. Zed Books.

Cassim, R., Onyango, D., & Van Seventer, D. E. (2004). The state of trade policy in South Africa. Trade and Industrial Policy Strategies (TIPS).

Cenedese, G., L. Sarno, and I. Tsiakas (2014). Foreign Exchange Risk and the Predictability of Carry Trade Returns, Journal of Banking and Finance 42, 302-313.

Chen, Y-C., and Rogoff, K. 2002. "Commodity Currencies and Empirical Exchange Rate Puzzles." IMF Working Paper 02/27 (Washington: International Monetary Fund).

Chinn, M. D. (2006). A primer on real effective exchange rates: Determinants, overvaluation, trade flows and competitive devaluation. Open economies review, 17(1), 115-143.

Chkili, W., & Nguyen, D. K. (2014). Exchange rate movements and stock market returns in a regime-switching environment: Evidence for BRICS countries. Research in International Business and Finance, 31, 46-56.

Darvas, Z. (2012). Real effective exchange rates for 178 countries: a new database. Working Paper 2012/06, Bruegel, 15 March 2012.

Das, S., & Roy, S. S. (2016). Exchange Rate Return Co-movements and Volatility Spillover: The Case of Emerging Market Economies. Available online at: https: // www. isid. ac. in/ ~epu /acegd2016/papers/SumanDas.pdf

Della Corte, P., L. Sarno, and I. Tsiakas (2009). An Economic Evaluation of Empirical Exchange Rate Models, Review of Financial Studies 22, 3491-3530.

Della Corte, P., L. Sarno, and I. Tsiakas.(2011). Spot and Forward Volatility in Foreign Exchange, Journal of Financial Economics 100, 496-513.

De Gregorio, J., Giovannini, A., and Wolf, H. (1994). International Evidence on Tradables and Nontradables Inflation." European Economic Review, 38, 6, 1225-1244.

Edwards, L., & Lawrence, R. (2008). South African trade policy matters Trade performance and trade policy. Economics of Transition, 16(4), 585-608.

Edwards, S., & Savastano, M.A. (1999). Exchange rates in emerging economies: What do we know? What do we need to know? Stanford University Conference on “Economic Policy Reform: What We Know and What We Need to Know,” September 17-19, 1998.

Engle, R. F., & Bollerslev, T. (1986). Modelling the persistence of conditional variances. Econometric reviews, 5(1), 1-50.

Goldfajn, I., & Valdes, R. (1999). The Aftermath of Appreciations. Quarterly Journal of Economics, 114 (1): 229-262.

Gujarati, D.N. (2009). Basic Econometrics. New York: McGraw Hill.

Hausmann, R., Panizza, U., & Stein, E. (2001). Why do countries float the way they float? Journal of Development Economics, 66, 2, 387-414.

IDC – Research and Information. (2013). The South African economy: An overview of key trends since 1994. Industrial Development Corporation of South Africa Limited, Sandton, Gauteng, South Africa.

Iyke, B. N. (2017). Exchange rate undervaluation and sectoral performance of the South African economy. Journal of Economic Studies, 44(4), 636-649.

Iyke, B. N., & Ho, S. Y. (2018). Real exchange rate volatility and domestic consumption in Ghana. The Journal of Risk Finance, 19(5), 513-523.

Lane, P. R., and Milesi-Ferretti, G. M. 2000. “Long-Term Capital Movements.” NBER Working Paper No. 8366 (Cambridge, MA: National Bureau of Economic Research).

MacDonald, R & Ricci, L.A. (2003). Estimation of the Equilibrium Real Exchange Rate for South Africa. IMF Working Paper No WP03/44.

MacDonald, R., & Ricci, L. A. (2004). Estimation of the equilibrium real exchange rate for South Africa. South African Journal of Economics, 72(2), 282-304.

McKinnon, R. 1963. “Optimum Currency Areas.” American Economic Review, 53, 4, 717-724.

Menkhoff, L., L. Sarno, M. Schmeling, and A. Schrimpf (2012). Carry Trades and Global Foreign Exchange Volatility, Journal of Finance 67, 681-718.

Montiel, P.J. 1997. “Exchange Rate Policies and Macroeconomic Management in ASEAN Countries,” in Macroeconomic Issues Facing ASEAN Countries, ed. by J. Hicklin, Robinson, D., and Singh, A. (Washington: International Monetary Fund).

Mundell, R. 1961. “A Theory of Optimum Currency Areas.” American Economic Review, 51(4): 657–665.

Musila, Jacob & Al-zyoud, Hussein. (2012). Exchange Rate Volatility and International Trade Flows in sub-Saharan Africa: Empirical Evidence, Journal of African Business, 13 (2): 115-122.

Ndambendia, H., & Ahmed, A. H. (2011). Effective real exchange rate volatility and economic growth in Sub-Saharan Africa: Evidence from panel unit root and cointegration tests. IUP Journal of Applied Finance, 17(1), 85-94.

Nishimura, Y., & Hirayama, K. (2013). Does exchange rate volatility deter Japan-China trade? Evidence from pre-and post-exchange rate reform in China. Japan and the World Economy, 25, 90-101.

Onyekwena, C., Taiwo, O., & Uneze, E. (2014). South Africa in BRICS: A bilateral trade analysis. Occasional Paper, 181.

O’Neill, J. (2001). Building Better Global Economic BRICs. Goldman Sachs. Available: http://www.goldmansachs.com/our-thinking/archive/building-better.html.

O’Sullivan, A., & Sheffrin, S. M. (2003). Economics: Principles in action. Upper Saddle River, New Jersey 07458: Pearson Prentice Hall.

Pearson, K. (1896). Mathematical contributions to the theory of evolution—III. Regression, heredity, and panmixia. Philosophical Transactions of the Royal Society of London, Series A 187: 253–318.

Pétursson, T.G. (2009). Does inflation targeting lead to excessive exchange rate volatility? Central Bank of Iceland, Working Paper No. 46. Available at http://www.sedlabanki.is/ lisalib/getfile.aspx?itemid=7333.

Ricci, L.A. (2003). South Africa’s Real Exchange Rate Performance. IMF Working Paper. IMF, Geneva.

Rodrik, D. (2008). The real exchange rate and economic growth. Brookings papers on economic activity, 2008(2), 365-412.

Samuelson, P. A. (1964). Theoretical Notes on Trade Problems, Review of Economics and Statistics 46, 2, 145-154.

Sarno, L., I. Tsiakas, and B. Ulloa (2016). What Drives International Portfolio Flows? Journal of International Money and Finance, 60, 53-72.

Singh, T. (2002). On the GARCH estimates of exchange rate volatility in India. Applied Economics Letters, 9(6), 391-395.

Takaendesa, P., Tsheole, T., & Aziakpono, M. (2006). Real exchange rate volatility and its effect on trade flows: New evidence from South Africa. Studies in Economics and Econometrics, 30(3), 79-97.

Vieira, F. V., Holland, M., da Silva, C. G., & Bottecchia, L. C. (2013). Growth and exchange rate volatility: a panel data analysis. Applied Economics, 45(26), 3733-3741.

Table 1: Descriptive statistics of national currency/US$ and their returns (1995M01 to 2017M01)

Statistic	REAL/USD	RUBLE/USD	RUPEE/USD	RMB/USD	RAND/USD
Panel A: Levels					
Mean	2.1071	47.4604	28.5962	8.0013	7.8346
Median	2.0323	45.9500	28.7825	7.9932	7.3300
Maximum	4.1172	68.6160	75.1723	8.0584	16.076
Minimum	0.8420	31.3700	4.0040	7.9622	3.5345
Std. Dev.	0.7461	8.9655	15.0084	0.0238	2.6997
Skewness	0.4317	0.7036	0.7604	0.3315	0.9035
Kurtosis	2.7882	2.9958	4.4452	1.8838	3.6369
Jarque-Bera	8.7250	21.867	48.6057	18.609	40.537
Probability	0.0127	0.0002	0.0000	0.0000	0.0000
Observations	265	265	265	265	265
Panel B: Returns					
Mean	0.500	-0.080	0.290	1.020	0.510
Median	0.490	-0.010	0.070	0.250	0.350
Maximum	53.860	2.640	7.690	51.430	16.510
Minimum	-16.860	-2.090	-6.850	-12.110	-12.030
Std. Dev.	0.0572	0.0051	0.0201	0.0549	0.0455
Skewness	3.3579	0.4513	0.4890	4.6268	0.4545
Kurtosis	32.1119	9.2576	5.7642	38.9198	3.9244
Jarque-Bera	9818.6270	439.6988	94.5728	15134.4700	18.4870
Probability	0.0000	0.0000	0.0000	0.0000	0.0001

Sum	1.3202	-0.2070	0.7659	2.7016	1.3345
Sum Sq. Dev.	0.8600	0.0067	0.1059	0.7916	0.5438
Observations	264	264	264	264	264

Source: Computed from the International Financial Statistics (IFS) compiled by the IMF.

Table 2: Descriptive statistics of monthly NEER and REER and their returns (1995M01 to 2017M01)

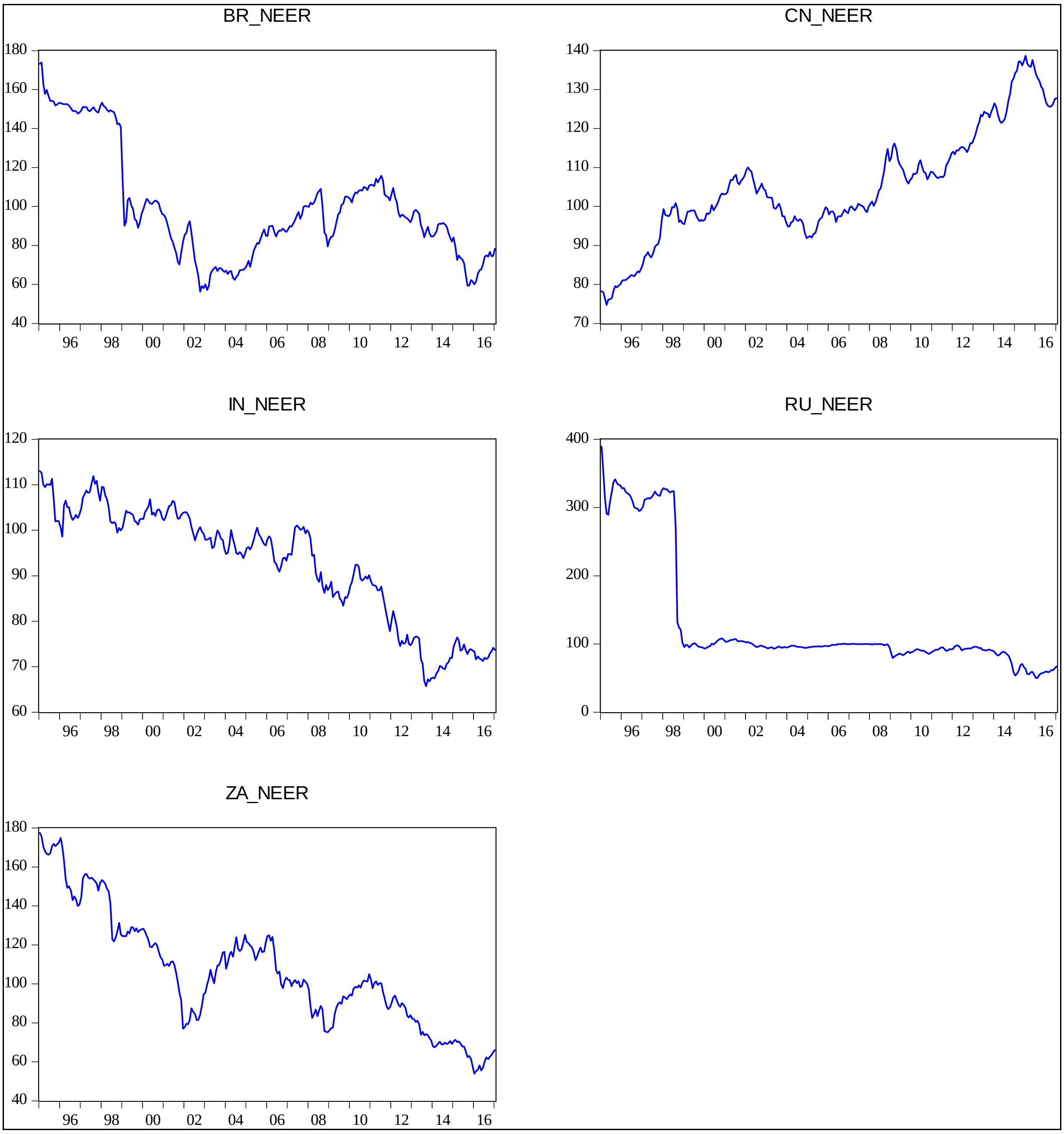
Panel A: NEER (in levels)					
Statistic	BR_NEER	CN_NEER	IN_NEER	RU_NEER	ZA_NEER
Mean	99.1778	105.0587	92.5264	129.1671	105.6341
Median	92.9878	102.4176	96.4036	96.2636	101.3143
Maximum	173.8653	138.6575	112.9956	389.4644	177.4959
Minimum	56.3320	74.7962	65.6946	50.4116	54.0051
Std. Dev.	28.3921	14.3559	12.6162	85.9352	29.4307
Skewness	0.8353	0.3449	-0.5564	1.7397	0.5038
Kurtosis	2.7742	2.8376	2.0723	4.2610	2.6238
Jarque-Bera	31.3757	5.5448	23.1766	151.2373	12.7745
Probability	0.0000	0.0625	0.0000	0.0000	0.0017
Sum	26282.1090	27840.5668	24519.4947	34229.2734	27993.0302
Sum Sq. Dev.	212813.3794	54408.5562	42020.1806	1949603.4519	228667.8428
Observations	265	265	265	265	265
Panel B: REER (in levels)					
Statistic	BR_REER	CN_REER	IN_REER	RU_REER	ZA_REER
Mean	92.0178	107.0546	95.9223	84.8626	99.4160
Median	96.1009	103.4189	92.6530	85.1632	100.5386
Maximum	125.9734	144.1286	118.3278	114.5707	127.0794
Minimum	47.8169	80.3148	73.3755	43.8834	65.7687
Std. Dev.	18.7502	14.9066	10.1698	18.6656	13.0182

Skewness	-0.3874	0.8392	0.4500	-0.2864	-0.2208
Kurtosis	2.0168	2.8988	2.4910	2.1856	2.5336
Jarque-Bera	17.3021	31.2195	11.8028	10.9461	4.5561
Probability	0.0002	0.0000	0.0027	0.0042	0.1025
Sum	24384.7245	28369.4731	25419.3983	22488.5889	26345.2411
Sum Sq. Dev.	92814.7827	58662.7746	27304.2707	91979.0078	44741.1173
Observations	265	265	265	265	265
Panel C: NEER returns					
Statistic	BR_NEER	CN_NEER	IN_NEER	RU_NEER	ZA_NEER
Mean	-0.300	0.190	-0.160	-0.670	-0.370
Median	-0.060	0.270	-0.110	0.030	-0.220
Maximum	11.390	0.0483	6.690	12.500	8.590
Minimum	-23.380	-3.470	-6.110	-72.170	-17.560
Std. Dev.	0.0385	0.0114	0.0159	0.0557	0.0319
Skewness	-1.7454	-0.0041	-0.2750	-8.4411	-1.2083
Kurtosis	11.3050	3.7974	4.8338	105.1848	7.6947
Jarque-Bera	892.7418	6.9953	40.3199	117994.1000	306.6916
Probability	0.0000	0.0303	0.0000	0.0000	0.0000
Sum	-0.7937	0.4898	-0.4275	-1.7594	-0.9888
Sum Sq. Dev.	0.3901	0.0341	0.0666	0.8163	0.2679
Observations	264	264	264	264	264
Panel D: REER returns					
Statistic	BR_REER	CN_REER	IN_REER	RU_REER	ZA_REER
Mean	-4.000	0.180	0.140	0.230	-0.130
Median	0.040	0.210	0.180	0.590	0.070
Maximum	11.41	4.260	7.340	13.110	9.090
Minimum	-22.76	-3.730	-4.880	-42.40	-16.990
Std. Dev.	0.0385	0.0119	0.0166	0.0415	0.0317
Skewness	-1.6272	-0.1600	0.1524	-4.4465	-1.0854
Kurtosis	10.9031	3.2524	4.6572	46.1331	7.1497
Jarque-Bera	803.5518	1.8277	31.2306	21335.0200	241.2605
Probability	0.0000	0.0401	0.0000	0.0000	0.0000
Sum	-0.0949	0.4668	0.3654	0.6033	-0.3344
Sum Sq. Dev.	0.3897	0.0371	0.0724	0.4520	0.2648
Observations	264	264	264	264	264

Note: BR_REER, CN_REER, IN_REER, RU_REER, and ZA_REER, denote, respectively, the REER returns of Brazil, China, India, Russia, and South Africa.

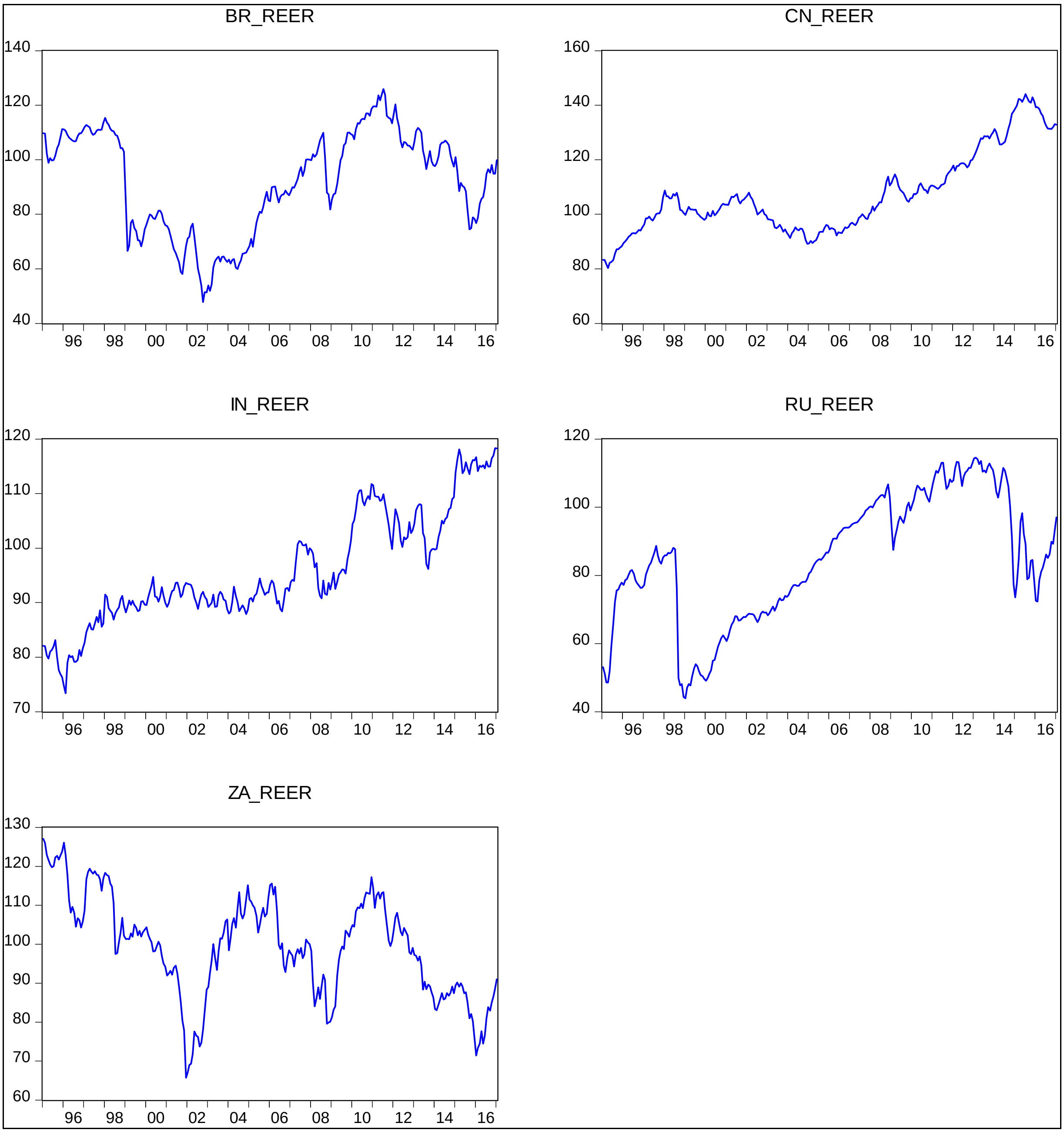
Source: Data obtained from Bruegel.org.

Figure 1a: Graph of monthly NEER (1995:01-2017:01)



Source: Data obtained from Bruegel.org

Figure 1b: Graph of monthly REER 1995:01-2017:01



Source: Data obtained from Bruegel.org

Figure 1c: Graph of monthly NEER returns (1995:01-2017:01)

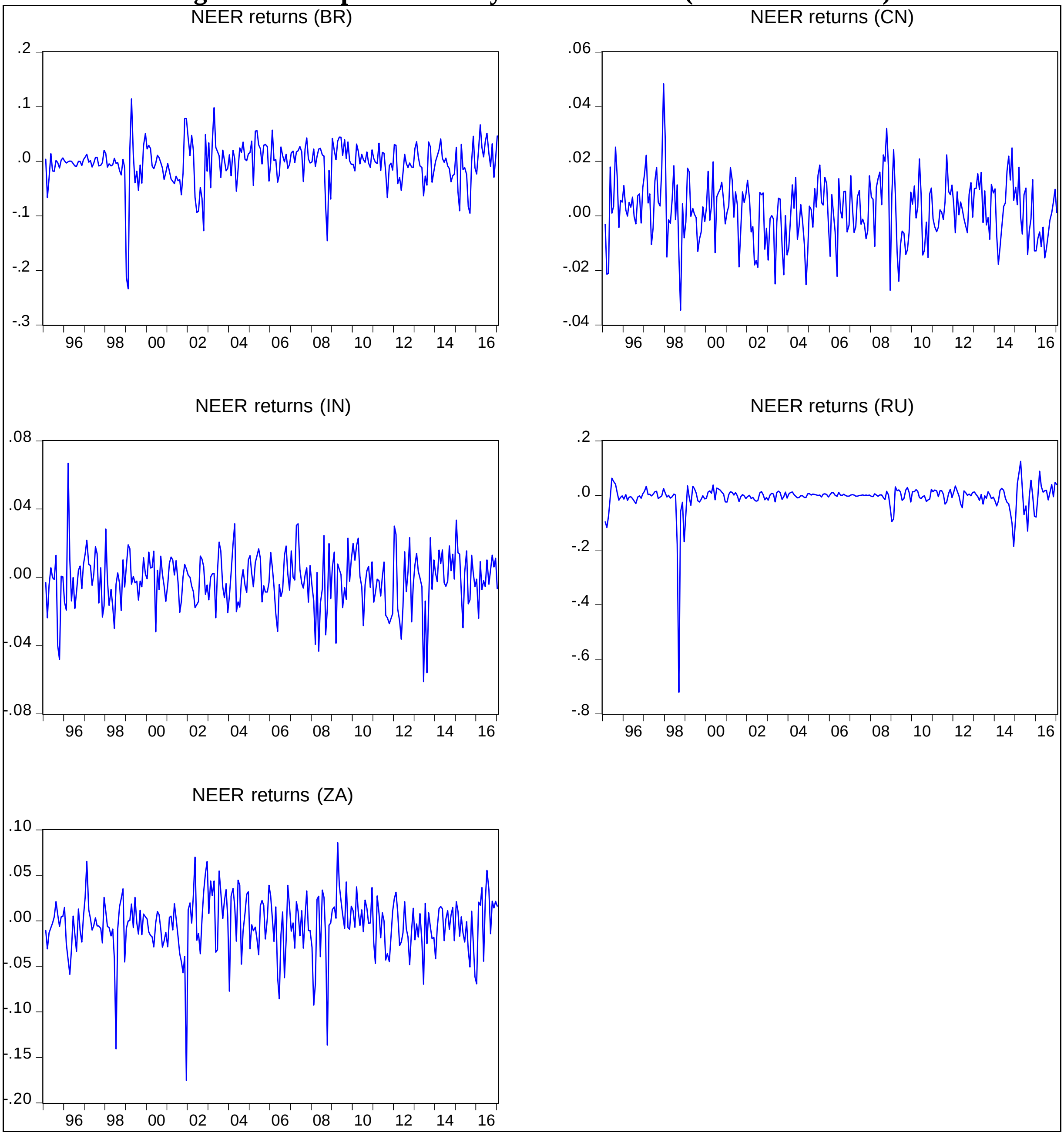


Figure 1b: Graph of monthly REER returns (1995:01-2017:01)

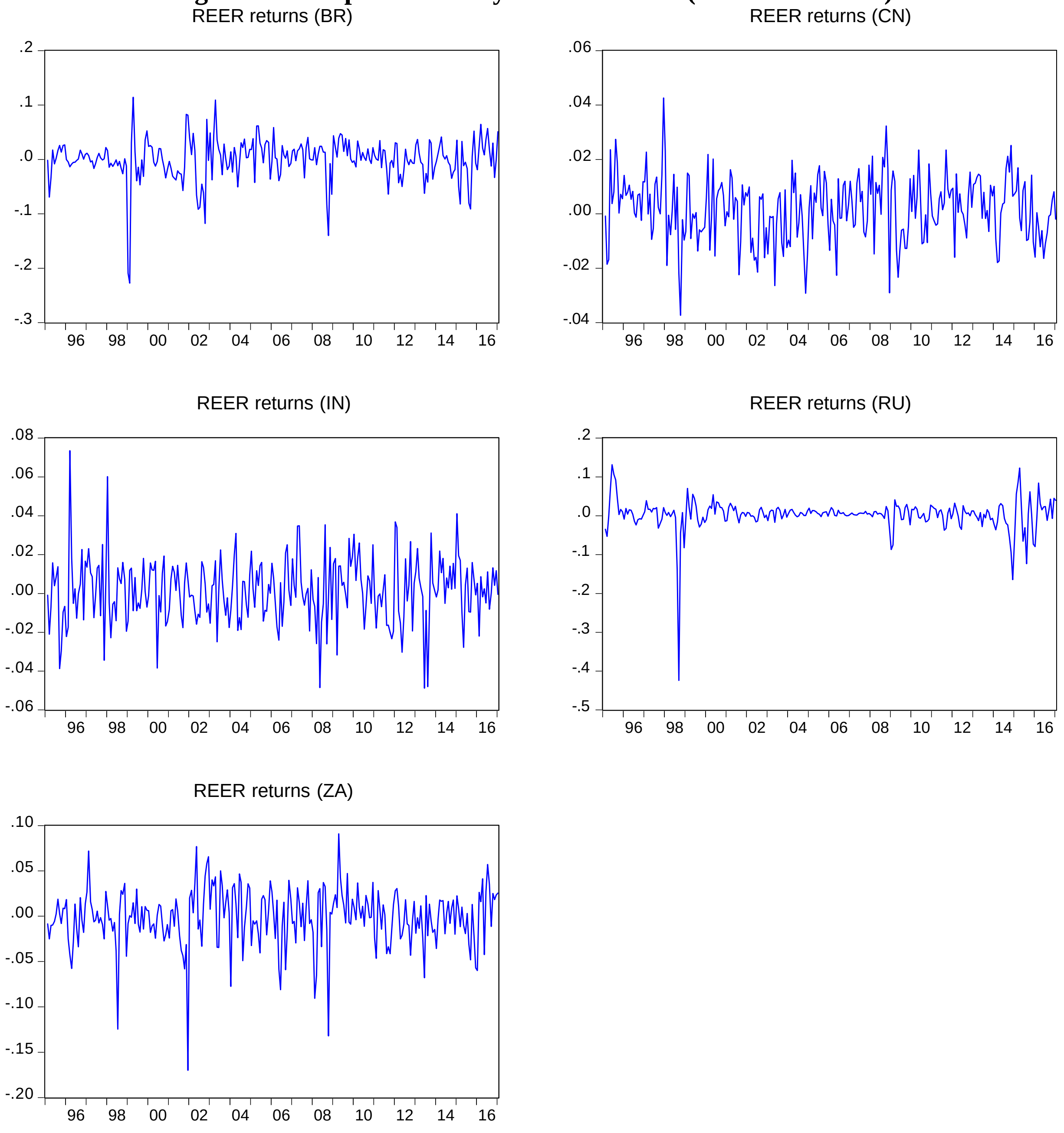


Table 3: Descriptive statistics NEER and REER return volatility

Panel A: NEER return volatility					
Statistic	BR_VOL	CN_VOL	IN_VOL	RU_VOL	ZA_VOL
Mean	0.120	0.010	0.020	0.260	0.110
Median	0.090	0.010	0.020	0.040	0.080
Maximum	1.330	0.030	0.060	26.000	0.920
Minimum	0.070	0.010	0.010	0.030	0.040
Std. Dev.	0.0013	0.0000	0.0001	0.0178	0.0010
Skewness	6.1404	2.4637	1.5056	12.7223	3.9912
Kurtosis	48.7488	9.7713	5.8104	175.6046	25.0997
Jarque-Bera	24587.9700	768.5080	185.9147	333569.3000	6050.2440
Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Sum	0.3272	0.0295	0.0639	0.6890	0.2972
Sum Sq. Dev.	0.0005	0.0000	0.0000	0.0828	0.0003
Observations	263	263	263	263	263
Panel B: REER return volatility					
Statistic	BR_VOL	CN_VOL	IN_VOL	RU_VOL	ZA_VOL
Mean	0.120	0.010	0.030	0.320	0.110
Median	0.090	0.010	0.030	0.040	0.080
Maximum	1.360	0.030	0.080	22.490	0.650
Minimum	0.070	0.010	0.020	0.0000	0.030
Std. Dev.	0.0013	0.0000	0.0001	0.0158	0.0008
Skewness	6.3032	2.5848	2.9084	11.6932	3.3024
Kurtosis	51.8680	11.9473	15.5257	155.9975	18.8216
Jarque-Bera	27910.8400	1170.1160	2090.0660	262508.7000	3221.1760
Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Sum	0.3261	0.0336	0.0719	0.8399	0.2797
Sum Sq. Dev.	0.0004	0.0000	0.0000	0.0652	0.0001
Observations	263	263	263	263	263

Source: Computed using data from Bruegel.org

Figure 2a: Graph of return volatility of NEER (1995:01-2017:01)

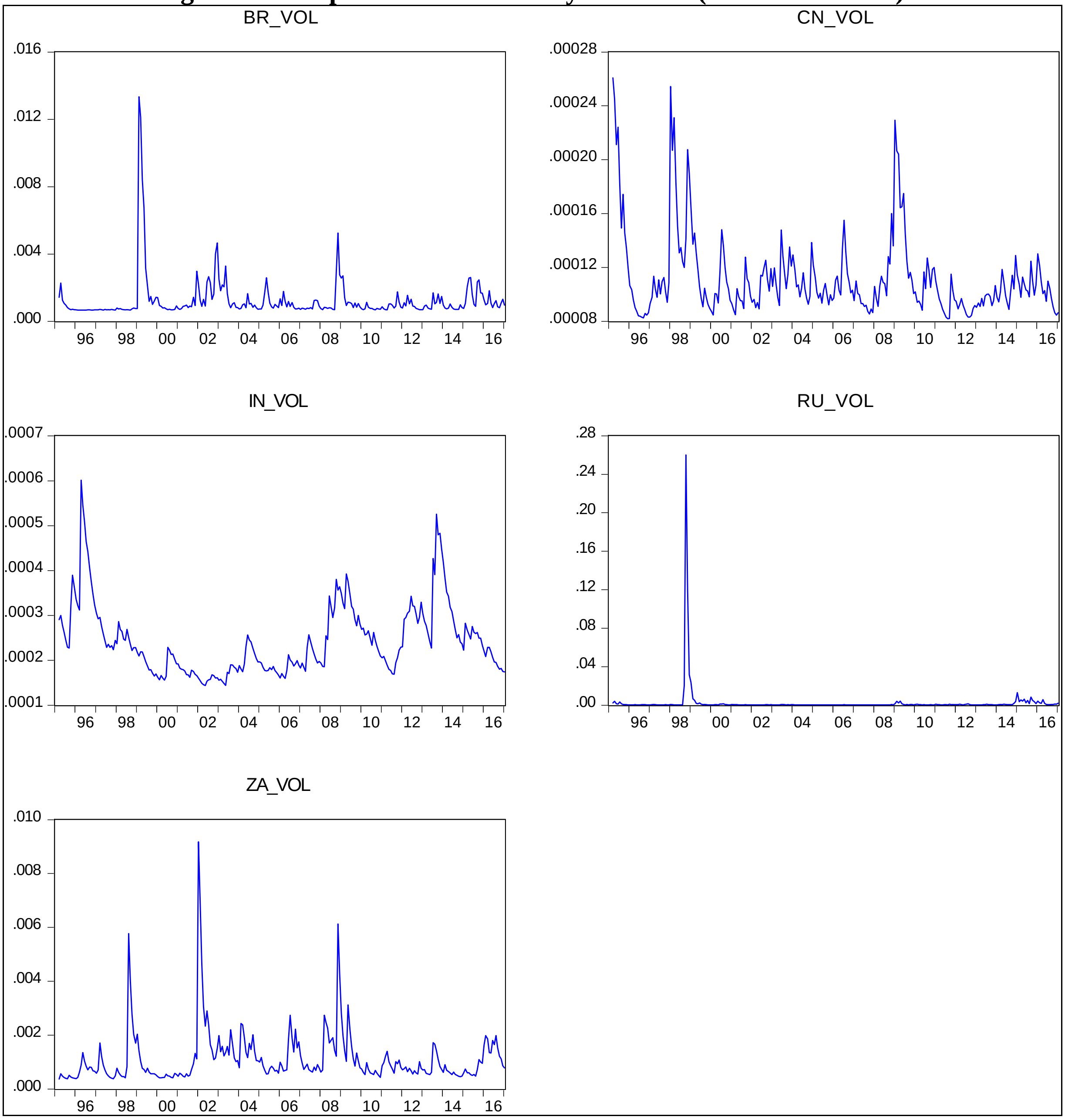


Figure 2b: Graph of return volatility of REER (1995:01-2017:01)

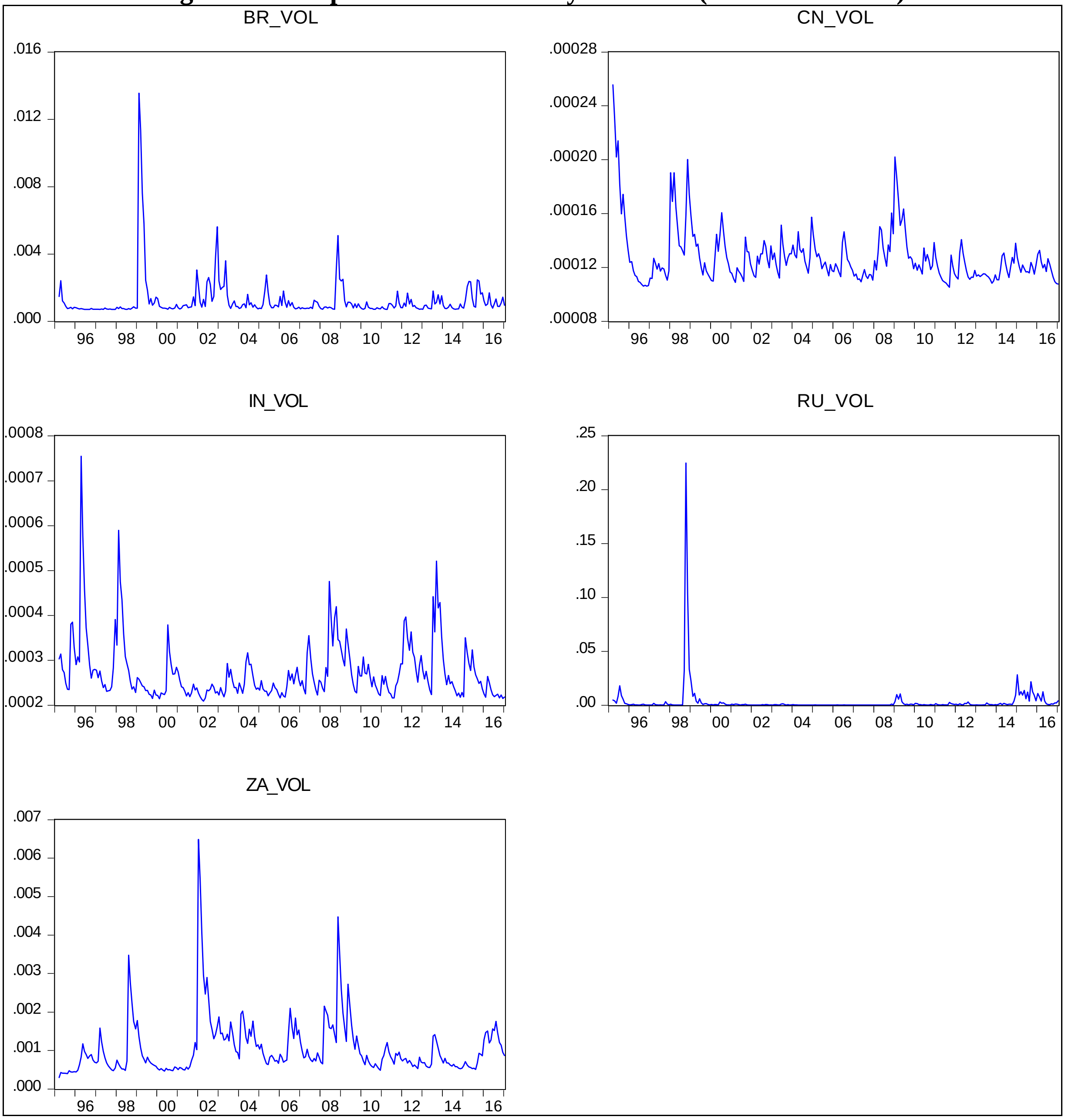


Table 4: Volatility dependence of currency returns

Correlation	BR_VOL	CN_VOL	IN_VOL	RU_VOL	ZA_VOL
Panel A: NEER return volatility					
BR_VOL	1.0000				
	[0.0000]				
CN_VOL	0.1421	1.0000			
	[0.0212]	[0.0000]			
IN_VOL	-0.0819	0.0864	1.0000		
	[0.1853]	[0.1623]	[0.0000]		
RU_VOL	-0.0077	0.1729	-0.0183	1.0000	
	[0.9006]	[0.0049]	[0.7675]	[0.0000]	
ZA_VOL	0.1341	0.0924	-0.0593	0.1281	1.0000
	[0.0297]	[0.0126]	[0.3383]	[0.0379]	[0.0000]
Panel B: REER return volatility					
BR_VOL	1.0000				
	[0.0000]				
CN_VOL	0.1336	1.0000			
	[0.0303]	[0.0000]			
IN_VOL	-0.0515	0.1445	1.0000		
	[0.4060]	[0.0190]	[0.0000]		
RU_VOL	0.0201	0.2351	-0.0583	1.0000	
	[0.7452]	[0.0001]	[0.3461]	[0.0000]	
ZA_VOL	0.1561	0.0968	-0.0430	0.1094	1.0000
	[0.0112]	[0.0113]	[0.4872]	[0.0767]	[0.0000]

Notes: P-values are in the block parentheses. The significance level is Bonferroni-adjusted. Pairwise correlations are based on Pearson (1896).

Figure 3a: Five-year rolling correlations between volatility of NEER returns

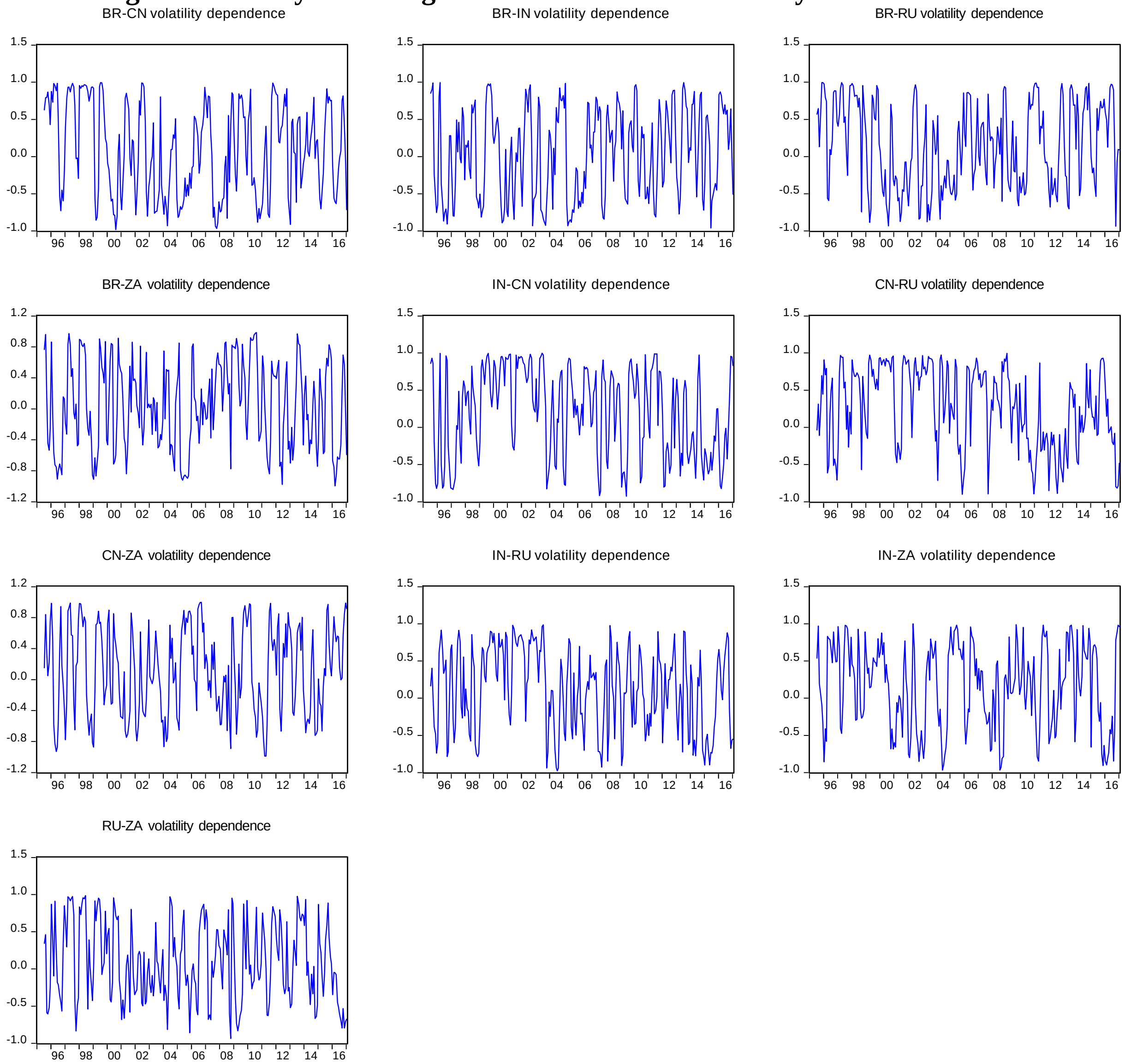


Figure 3b: Five-year rolling correlations between volatility of REER returns

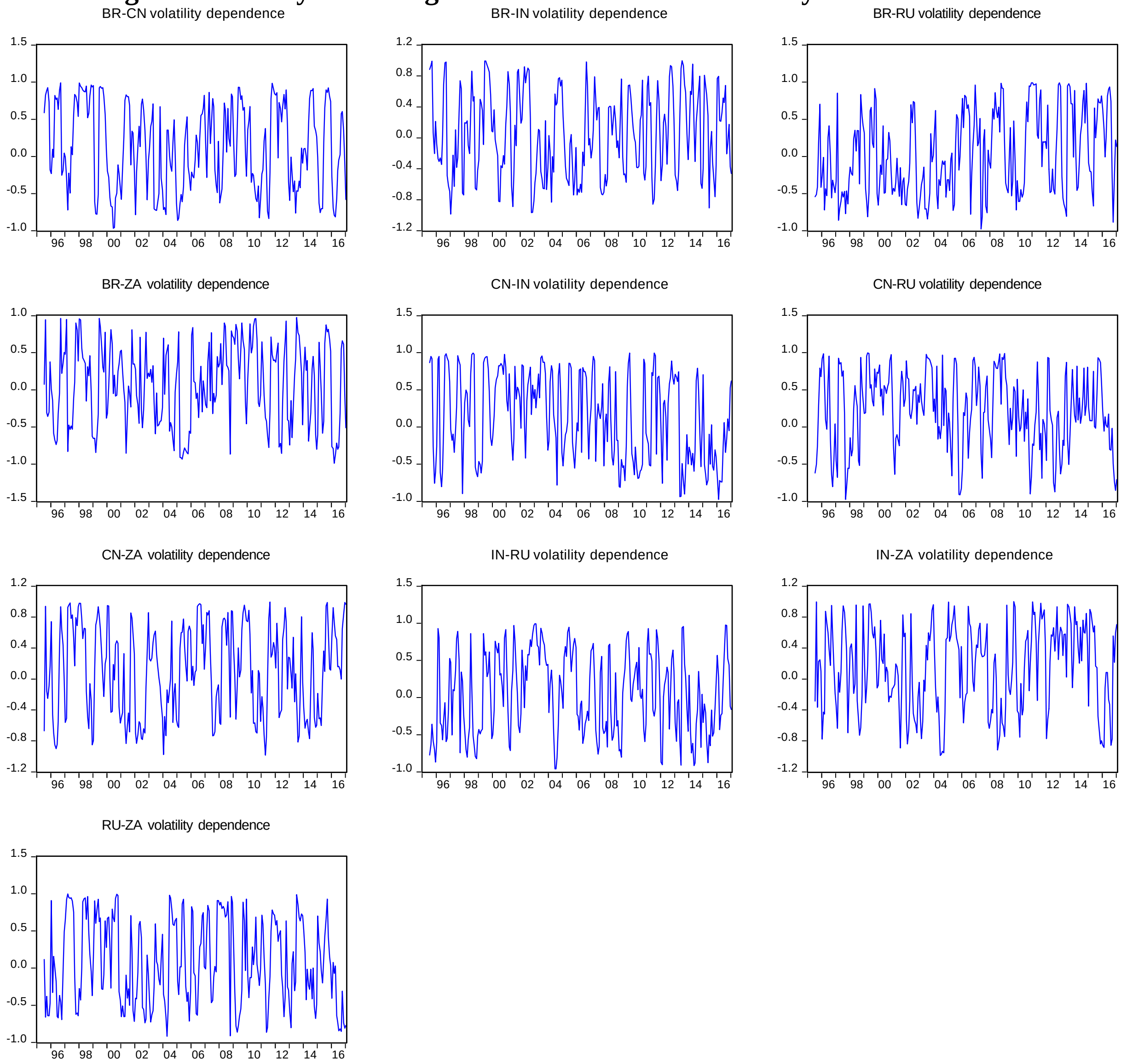


Table 5: Bivariate Granger Causality of currency returns (1995:01-2017:01)

Null Hypothesis	F-Statistic	P-value	F-Statistic	P-value
	NEER returns		NEER returns	
CN does not cause BR	2.7349	0.0018	2.9230	0.0009
BR does not cause CN	0.4765	0.9272	0.7444	0.7070
IN does not cause BR	0.4092	0.9591	1.2323	0.2619
BR does not cause IN	0.3108	0.9871	0.4241	0.9530
RU does not cause BR	58.7437	0.0000	46.6395	0.0000
BR does not cause RU	0.0654	1.0000	0.0902	1.0000
ZA does not cause BR	4.2469	0.0000	3.3444	0.0002
BR does not cause ZA	0.7158	0.7354	0.7609	0.6903
IN does not cause CN	0.3883	0.9669	1.2600	0.2438
CN does not cause IN	0.9307	0.5170	1.2133	0.2747
RU does not cause CN	1.3187	0.2088	1.4771	0.1339
CN does not cause RU	12.0339	0.0000	6.2098	0.0000
ZA does not cause CN	0.9893	0.4600	1.2946	0.2226
CN does not cause ZA	2.1908	0.0130	1.9266	0.0324
RU does not cause IN	0.1440	0.9997	0.1329	0.9998
IN does not cause RU	0.3438	0.9800	3.1788	0.0003
ZA does not cause IN	0.1486	0.9996	0.2105	0.9979
IN does not cause ZA	1.0666	0.3895	0.9682	0.4802
ZA does not cause RU	3.9104	0.0000	2.4935	0.0043
RU does not cause ZA	0.1468	0.9997	0.1290	0.9998

Notes: Causality is understood as Granger Causality. Lags of 12 are used in the estimation.