Exchange Rate Dynamics and Passthrough in the BRICS: An ARDL Bounds Testing Approach Investigation

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Abstract

This article aims at analyzing issues related to exchange rate dynamics and passthrough in the BRICS countries (Brazil, Russia, India, China and South Africa), for the period ranging from January 2005 to December 2019. By making use of ARDL Bounds Testing Approach to Cointegration methodology, our results show that: i) there is long run cointegration between the variables analyzed for all estimated models; ii) there is no indication of Dornbusch's exchange rate overshooting phenomenon; iii) most of the short run coefficients for international reserves are negative, in first difference, meaning that foreign reserve accumulation can be, at least partially, a possible explanation for the evidence of no exchange rate overshooting; iv) there is indication of passthrough from exchange rate movements to domestic inflation, but such phenomenon doesn't seem to be so strong as before; v) whenever a short run shock occurs, there is a slow speed of adjustment towards the long run equilibrium, for both exchange rate and prices, averaging 8.6% for the exchange rate determination model, and 3.1% for the exchange rate passthrough model.

Key Words: Exchange Rate, Inflation, Overshooting, Passthrough, ARDL, Cointegration

JEL Classification: C22, F14, F17

Resumo

Este artigo analisa questões relacionadas à dinâmica da taxa de câmbio e ao repasse cambial nos BRICS (Brasil, Rússia, Índia, China e África do Sul), para o período de janeiro de 2005 a dezembro de 2019. Utilizando a abordagem ARDL Bounds Testing para Cointegração, os resultados indicam que: i) há evidências de cointegração de longo prazo entre as variáveis analisadas em cada modelo analisado; ii) não há indicação do fenômeno da ultrapassagem (overshooting), como no modelo do Dornbusch; iii) a maioria dos coeficientes de curto prazo estimados para as reservas internacionais são negativos, em primeira diferença, corroborando a suspeita de que maiores níveis de reservas acumuladas podem ser, pelo menos parcialmente, uma possível explicação para a evidência de não ocorrência da ultrapassagem da taxa de câmbio. iv) existe indicação da ocorrência de repasse (passthrough) dos movimentos da taxa de câmbio para a inflação doméstica, embora tal repasse não seja tão pronunciado; v) quando um choque de curto prazo ocorre, há lenta velocidade de ajuste em direção ao equilíbrio de longo prazo, tanto para a taxa de câmbio quanto para os preços, com respectivas médias de 8,6% (modelo de dinâmica cambial) e 3,1% (modelo de repasse cambial).

Palavras-chave: Taxa de Câmbio, Inflação, Ultrapassagem, Repasse Cambial, ARDL, Cointegração

Classificação JEL: C22, F14, F17

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Introduction

Topics related to exchange rate dynamics have always been subject to analysis by economists and researchers in general, as they impact everyone's lives in many ways, such as in business and trade. In economics, specifically, there are some important phenomena that are worth mentioning and studying. One of them is the consequence of excessive fluctuation and volatility of exchange rate, which can lead to Dornbusch's (1976) overshooting phenomenon. Another one, known as exchange rate passthrough, is related to the way prices respond to the foreign currency movements, i.e., how domestic inflation is affected by changes in the exchange rate.

Once we go back to the international economic scenario in the early 1970s, when Bretton Woods system collapsed, one of the key issues was the danger of adopting expansionist monetary policies with a flexible exchange rate regime, since this lead to higher inflation and more volatile exchange rates. Dornbusch (1976) showed that, given price rigidity, advanced economies would face an initial exchange rate overshooting but, as prices changed, convergence would eventually occur to its equilibrium level.

Another argument is associated to the fact that, since the international financial crisis, many advanced and emerging economies adopted expansionary monetary and fiscal policies. This action led to the zero lower bound interest rate phenomenon in advanced economies but were not associated with increasing inflation. This could be an indication that the monetary transmission mechanism did not work as expected impact, even after some time. The question to be addressed is that if, in this new scenario, monetary shocks behave in the same way as predicted by Dornbusch (1976), for the BRICS countries (Brazil, Russia, India, China and South Africa).

One of the paper's motivation is to address these phenomena in a different world economy, mostly after the 2007-08 international financial crisis, and focusing on a different set of economies, emerging (BRICS) rather than advanced countries. A key feature of this period, in the BRICS case, is that they faced periods of terms-of-trade improvements, especially due to increases in commodity prices. This scenario was favorable for accumulation of international reserves, helping mitigate, or even neutralize, excessive exchange rate volatility. Just to give an idea of international reserve accumulation in the BRICS, between January 2005 and December 2019, the growth rates are: Brazil (560%), Russia (266%), India (245%), China (398%) and South Africa (264%).

But the high volume of capital flows and foreign reserve accumulation in the past decades are important components of exchange rate determination, nowadays. There is no doubt that international reserves have been used decrease exchange rate volatility and, as a result, to cushion external shocks to the balance of payments. Another argument for this article is associated to the investigation of exchange rate passthrough, based on the argument that, in a more globalized world environment, exchange rate movements are more likely to have an impact on domestic prices and, consequently, on inflation.

When bringing this discussion to the reality of the BRICS, these countries can be seen as major emerging market economies, as they account altogether 25% of global GDP, and about half of the world's population. International trade plays an important role in their economic growth, making their trade balance and inflation highly dependent exchange rate fluctuations. As a result, there are similarities and differences in how exchange rate movements affect the economy of the BRICS countries, in the short run and long run, and how governments respond to exchange rate dynamics and passthrough in these nations.

This article aims to analyze issues related exchange rate dynamics and passthrough in the BRICS countries, for the period ranging from January 2005 to December 2019. By making use of ARDL Bounds Testing Approach to Cointegration methodology, our results show some important characteristics: i) there is long run cointegration between the variables analyzed for all BRICS countries; ii) there is no indication of Dornbusch's exchange rate overshooting phenomenon; iii) most of the short run coefficients for international reserves are negative, in first difference, meaning that foreign reserve accumulation can be, at least partially, a possible explanation for the evidence of no exchange rate overshooting; iv) there is indication of passthrough from exchange rate movements to domestic inflation, even though such phenomenon doesn't seem to be so strong anymore; v) whenever a short run shock occurs, there is a slow speed of adjustment towards the long run equilibrium, for both exchange rate and prices, averaging 8.6% for the exchange rate determination model, and 3.1% for the exchange rate passthrough model.

Besides this introduction, this paper reviews the literature related to exchange rate dynamics and exchange rate passthrough in section 2. Section 3 is dedicated to the econometric methodology and data. Section 4 reports the results and the last section draws some conclusions.

2. The Literature

There is a vast literature on issues related to monetary models of exchange rate determination, which were developed after the collapse of fixed exchange rates system in the early 1970s. These approaches are usually based on Mundell-Fleming's modeling strategy. The first one is the monetary/asset view (flexible price) model, as in Frenkel (1976) and Bilson (1978). This line of research works with types of exchange rate determination models more connected with asset markets, with special emphasis to the role of expectations and arbitrage conditions. The second one is the sticky price-asset monetary model, as in Hooper and Morton (1982). The third one is the sticky price/real interest rate differential, as in Dornbusch (1976) and Frankel (1979).

Dornbusch's overshooting model is still a popular way of understanding the implications of temporary demand-side (monetary) shocks for short-run movements of nominal exchange rates and relative prices, given that goods prices are sticky in the short-run. In the long run, the model assumes purchasing power parity, i.e., a constant long-run real exchange rate. Dornbusch's argument is that that temporary demand-side shocks influence nominal exchange rates only via relative price effects, whereas real factors (long run) movements will only affect the nominal exchange rate, but not relative prices.

Frankel (1979) developed a monetary (asset) approach of exchange rate determination to examine the role of expectations, as well as some other characteristics of exchange rate market efficiency. The author's empirical results are coherent with the monetary view. Flood (1979) also analyzed the exchange rate overshooting case and said that, as the process of asset market clearing is much faster than in other markets, exchange and interest rates are usually responsible for short run adjustments to guarantee asset balance.

Kim and Roubini (2000) found little evidence of open economy anomalies, with exchange rate responding with appreciation to a restrictive monetary policy. Over time, there is depreciation of exchange rate, in a type of delayed exchange rate overshooting. This "delayed overshooting puzzle" was also examined by Kim (2005) and Kim, Moon and Velasco (2017).

Cavallo et al. (2005) detected some exchange rate overshooting; i) during the 1998/99, in the case of Brazil; ii) during the 1995 Indian crisis, in the case of India; iii) In 1996 and 1998 for the South African case; iv) in 1998 for the case of Russia. Maitra (2016) found indication of exchange rate overshooting phenomenon and Barnett, Bhadury and Ghosh (2016) saw signs of delayed overshooting, in the case of India. For the Brazilian case, Kim and Henry Kim (2007) found that, in the 1994–95 Mexico crisis, Brazil underwent a significant exchange rate overshooting experience, which happened again in the 1998/99 Real devaluation crisis. As for South Africa, the country also faced the same problem during the 1997/98 Asian financial crisis.

Rogoff (2002) is a must-read article if one wants to know about Dornbusch's overshooting, showing an overview of the model and some empirical results related to measures of the article's impact. Other articles also researched the overshooting phenomenon, such as: Hairault, Patureau and Sopraseuth (2004), Bahmani-Oskooee and Panthamit (2006), Bjørnland (2009), Tu and Feng (2009), Lee (2016), Feuerriegel, Wolff and Neumann (2016),

There is also vast literature showing evidence that long-run real exchange rates cannot be taken as constant. In this case, the long-run real exchange rate is modelled using real resource allocation models, such as Balassa (1964), Samuelson (1964) and Stein (1995). Basically, the well-known Balassa–Samuelson effect argues that inflation tends to be higher in poorer countries due to productivity differences. Balassa (1964) showed that the relationship between PPP and exchange rates can be enhanced by including non-traded goods in the discussion. Stein (1995) found strong evidence that real exchange rates, in developed and developing countries, are cointegrated along with long-run real factors, such as productivity. Thus, there is evidence that the findings of the long-run real exchange rate literature support the findings in the PPP literature that long-run real exchange rates are not constant, i.e., PPP does not hold as a long-run relationship.

Research on the relationship between foreign reserves and exchange rate determination is also abundant and important. For example, Edwards (1984) examined a sample of developing countries and concluded that foreign reserve accumulation depends on monetary factors and on differences between actual and desired reserves. Focusing specially on emerging market economies, Rodrik (2006) argued that the rapid accumulation of foreign reserves in these economies could be more connected to avoiding exchange rate appreciation, and keeping trade competitiveness abroad, than to a self-insurance reason. Aizenman and Lee (2007) said that these countries usually accumulate international reserves for precautionary reasons. Reinhart and Reinhart (2011) analyzed data for 100 economies and found that emerging market countries avoid exchange rate fluctuations through accumulation of international reserves. Aizenman and Hutchison (2012) found that emerging market countries opted not to lose reserves during the 2008 financial crisis, letting currency depreciate for the shock to be absorbed.

Aizenman et al. (2015) found some differences between the periods before and after the 2008 financial crisis. According to the authors, before the crisis, emerging market economies used to accumulate international reserves due to savings reasons. However, after the crisis, the authors found the opposite (higher gross saving related to lower foreign reserve holding). In addition to that, they found that the quantitative easing tapering, after 2012, made emerging market countries, with low reserve accumulation, experience exchange rate depreciation. Pina (2015) analyzed data for developing countries, from 1970 to 2009, and concluded that a satisfactory amount of foreign reserve depends on actions coming from monetary authorities towards managing inflation and exchange rate.

Another important line of research has to do with exchange rate passthrough which, as mentioned previously, is related to the connection between inflation and exchange rate dynamics. Goldberg and Knetter (1997), for instance, stated that incomplete passthrough can be a result of consequence of third-degree price discrimination. Burstein, Eichenbaum and Rebelo (2007) argued that inflation targeting played a key role in decreasing passthrough effects. But through the analysis of the cases of Korea, Uruguay and UK, the authors showed that exchange rate effects on inflation are still important for emerging market inflation targeters.

Campa and Goldberg (2005) analyzed the case of 23 OECD countries and found evidence of higher passthrough elasticities within countries that exhibit high levels of exchange rate volatility, despite a decrease in importance of macroeconomic variables in the determination of passthrough elasticities. The authors also said that changes in the composition of imported goods are more relevant for passthrough dynamics. Jašová, Moessner and Takáts (2019) found that, after the 2007-08 global financial crisis, exchange rate passthrough remained stable and low in advanced countries. As for emerging market countries, exchange rate passthrough decreased, mainly due to a decrease in inflation.

Ha, Stocker, Yilmazkuday (2019) analyzed the exchange rate passthrough to inflation in 47 economies and found that such phenomenon varies considerably amongst countries, mainly because of economic policy characteristics and sensitivity to exchange rate fluctuations. The authors also found that passthrough ratios tend to be lower with a credible IT framework, central bank independence and with flexible exchange rate regimes.

Caselli and Roitman (2019) examined data from 27 emerging market economies, from 1990 to 2013, finding that appreciation and depreciation episodes have asymmetric impacts on inflation and, therefore, cause asymmetric exchange rate passthrough effects. The authors also pointed that inflation targeting seems to cause some reduction on exchange rate passthrough.

Jiménez-Rodríguez and Morales-Zumaquero (2020) examined exchange rate passthrough hypothesis for the BRICS countries. Brazil, Russia and South Africa are the ones with most exchange rate volatility, which might influence the magnitude of their passthrough cases. The authors also stated that, differently from the case of China and India, exchange rate plays an important role in explaining inflation variability in Brazil, Russia and South Africa. Finally, as the BRICS countries have had a growing share in global trade, the degree of openness is a key macroeconomic variable for exchange rate passthrough determination.

Nogueira Jr. (2007) also searched for evidence of exchange rate passthrough in emerging market economies and found that the phenomenon declined after IT, but it has not disappeared, especially in the long run. Reyes (2007) also saw IT adoption as important for a decrease in exchange rate passthrough in emerging market countries, but it is still a relevant matter and cannot be neglected.

Egert and Macdonald (2009) concluded that exchange rate passthrough mechanism has decreased considerably over time, in Central and Eastern Europe countries, mainly due to lower inflation rates. Aron, Macdonald, Muellbauer (2014) also survey the literature related to exchange rate passthrough for several countries and find little difference between the cases of emerging and advanced economies. The authors also found some signs that exchange rate volatility might be correlated with higher exchange rate passthrough in emerging market countries.

Other articles have examined the exchange rate passthrough phenomenon in the BRICS countries. For the case of Brazil: Belaisch (2003), Muinhos (2004), Correa and Minella (2010); India: Dash and Narasimhan (2011), Mallick and Marques (2008); Yanamandra (2015). China: Jiang and Kim (2013); Bouvet, Ma and Van Assche (2017). South Africa: Karoro, Aziakpono, and Cattaneo (2009); Aron, Farrel, Muellbauer, and Sinclair (2014); Aron, Creamer, Muellbauer, and Rankin (2014).

3. Econometric Approach and Data

Pesaran and Shin (1999) and Pesaran et al. (2001) proposed a cointegration analysis based on Autoregressive Distributed Lag (ARDL), which originated the so-called ARDL-Bounds Testing Approach to Cointegration. This approach has some advantages over other cointegration methodologies, such as the ones developed by Engle and Granger (1987), Phillips and Hansen (1990) and Johansen (1991). For instance, Pesaran's approach allows for the use of a mix of variables (stationary, non-stationary, or mutually cointegrated) and tend to work better with small samples, better capturing the long run relationship in these cases. On the other hand, the methodology is not suitable for I(2) variables.

The ARDL-Bounds Testing Approach to Cointegration makes use of critical values for the F statistics calculated: i) upper bound: of the ARDL model are non-stationary I(1), meaning that there is cointegration; ii) lower bound: all variables of the ARDL model are stationary I(0), meaning that there is no cointegration; iii) between bounds: inconclusive test (Pesaran et al., 2001).

This possible third case, the F-statistics falling between the critical values calculated by Pesaran et al. (2001), is the reason why it is important to run and analyze some conventional unit root tests before starting to apply the ARDL-Bounds Testing Approach. Unit root tests are also important to check whether there is any I(2) variable. Therefore, by making use of unit root tests results, the researcher can decide whether Pesaran's methodology is suitable or not (Table 1).

After running the basic ARDL model, and before moving further with an analysis of short and long run dynamics, the researcher must verify whether the lag selection, made through the use of selection criteria, was able to eliminate any autocorrelation problem in all estimated models. This can be done by running a conventional autocorrelation LM test, with the null of no autocorrelation. Another essential diagnostic test has to do with parameter stability. In this case, Cumulative Sum (CUSUM) and Cumulative Sum of Squared (CUSUMSq) Recursive Residuals tests can be applied, as proposed by Brown, Durbin and Evans (1975). Both CUSUM and

CUSUMSq residual tests help identify possible structural break problems in the estimated models. Parameter instability is detected when any, or both test results, falls outside the 5% critical lines.

The ARDL-Bounds Testing Approach is able to retain information on both short and long run properties of the estimated model. Whenever there is a short run shock, an adjustment process takes place to bring back the long run equilibrium. In other words, once the cointegration is confirmed, it is possible to estimate the long-run equilibrium coefficients, as well as the short-run coefficients together with the Error Correction Mechanism (ECM) itself. The ECM coefficient is responsible for showing the adjustment speed towards the long run.

As mentioned previously, our estimated exchange rate determination model includes, as control variables: inflation, M3, interest rate and industrial production. All of them are expressed relative to the U.S. The model is extended with international reserves since this has been a relevant variable, especially after the 2007-08 international financial crisis, in order to reduce future risk of financial crisis and/or to serve as a cushion to minimize external shocks to the exchange rate. As for the estimated passthrough model, we use CPI as the dependent variable and exchange rate, industrial production and oil price as explanatory variables, all of them in natural log.

The empirical analysis developed in this work is based on Autoregressive Distributed Lag (ARDL) models applied to cointegration. In order to investigate the BRICS countries' exchange rate and price models, the following Error Correction Model (ARDL-ECM) ARDL equations will be estimated, for the period ranging from January 2005 to December 2019:

Exchange Rate Determination – Monetary Model

$$\Delta EXCRATE_t = \alpha_0 + \alpha_1\tau + \delta_1 EXCRATE_{t-1} + \delta_2 BROADMONEY_{t-1} + \delta_3 INFLATION_{t-1} + \delta_4 INTEREST_{t-1} + \delta_5 INDPROD_{t-1} + \delta_6 RESERVES_{t-1} + \sum_{i=1}^{n}\theta_1\,\Delta EXCRATE_{t-i} + \sum_{i=1}^{m}\theta_2\,\Delta BROADMONEY_{t-i} + \sum_{i=1}^{p}\theta_3\,\Delta INFLATION_{t-i} + \sum_{i=1}^{q}\theta_4\,\Delta INTEREST_{t-i} + \sum_{i=1}^{r}\theta_5\,\Delta INDPROD_{t-i} + \sum_{i=1}^{s}\theta_6\,\Delta RESERVES_{t-i} + \varepsilon_{1t} \quad (1)$$

Exchange Rate Passthrough

$$\Delta CPI_t = \alpha_0 + \alpha_1\tau + \delta_1 CPI_{t-1} + \delta_2 EXCRATE_{t-1} + \delta_3 PROD_{t-1} + \delta_4 PET_{t-1} + \sum_{i=1}^{n}\theta_1\,\Delta CPI_{t-i} + \sum_{i=1}^{m}\theta_2\,\Delta EXCRATE_{t-i} + \sum_{i=1}^{p}\theta_3\,\Delta PROD_{t-i} + \sum_{i=1}^{q}\theta_4\,\Delta OIL_{t-i} + \varepsilon_{2t} \quad (2)$$

where all variables are in natural log, except for inflation and interest rate:

- **Exchange Rate:** Nominal Exchange Rate (Local Currency Unit/US$). Source: IFS (IMF).
- **M3:** M3 relative to the U.S. (US$ million). Source: IFS (IMF) and FRED St Louis.
- **Inflation:** CPI Inflation Rate (%) minus U.S. CPI Inflation Rate (%). Source: IFS (IMF).
- Interest Rate: Money Market Rate (%) minus U.S. rate. For China: Call Money Interbank Rate minus the U.S. Rate. Source: IFS (IMF) and FRED (Federal Reserve Bank).
- **Relative Industrial Production:** Industrial Production relative to the U.S. (2010 = 100). For South Africa: Manufactured Production relative to the U.S. (2010 = 100). Source: IFS (IMF) and FRED (Federal Reserve).
- **International Reserves:** Intern. Reserves, excluding gold, in US$. Source: IFS (IMF).
- **CPI:** CPI index (2010 = 100). IFS (IMF).
- **Industrial Production:** Industrial Production. For South Africa: Manufactured Production. (2010 = 100). Source: IFS (IMF) and FRED (Federal Reserve).
- **Oil Price:** Oil Price in US$. Source: Primary Commodity Prices (IMF).

4. Results: ARDL-Bounds Testing Approach

Before running the ARDL models, we estimate some conventional unit root tests: Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Kwiatkowski-Phillips-Schmidt-Shin (KPSS). As mentioned previously, this is important to check whether there is any I(2) variable, which makes ARDL-Bounds Testing Approach unsuitable, and also to help the researcher decide As Table 1 makes clear, the results related to some variables are inconclusive, especially those associated to Industrial Production (South Africa), CPI (South Africa), Interest Rate (South Africa), M3 (India and Russia), Relative Industrial Production (India and Russia), and International Reserves (India and South Africa). Therefore, this makes ARDL-Bounds Testing Approach applicable whether to go on with the methodology if the F-statistics falls between bounds.

Table 1: Unit Root Tests

		ADF	PP	KPSS
Exchange Rate	Brazil	0.449	0.488	0.344**
	China	-2.291	-2.271	0.410**
	India	-2.787	-2.456	0.151*
	Russia	-2.735	-2.220	0.233**
	South Africa	-2.645	-2.367	0.158*
Industrial Production	Brazil	-2.465	-2.304	0.318**
	China	-6.452**	-6.914**	0.060
	India	-2.488	-1.986	0.280**
	Russia	-2.563	-2.831	0.065
	South Africa	-2.463	-2.930*	0.107
CPI Index	Brazil	-2.160	12.520	0.225**
	China	-2.316	-2.215	0.293**
	India	-1.718	-0.956	0.364**
	Russia	-1.953	-2.699	0.273**
	South Africa	-3.838*	-0.825	0.235**
Interest Rate	Brazil	-2.306	-1.727	0.132
	China	-1.075	-0.915	0.335**
	India	-0.340	-0.394	0.367**
	Russia	-2.175	-2.077	0.981**
	South Africa	-2.704	-0.585	0.137
M3	Brazil	-2.551	-2.735	0.383**
	China	0.059	0.256	0.438**
	India	-3.084*	-2.770	0.228**
	Russia	-2.873*	-2.962*	0.349**
	South Africa	-2.497	-2.358	0.273**
Relative Industrial Production	Brazil	0.065	0.216	0.382**
	China	0.034	-1.657	1.289**
	India	-3.584**	-3.781**	0.310**
	Russia	-3.258	-4.481**	0.287**
	South Africa	-3.875**	-7.550 **	0.288
Inflation	Brazil	-7.054**	-6.737**	0.276
	China	-3.390 *	-9.441**	0.088
	India	-10.283**	-10.228**	0.161
	Russia	-6.995**	-6.349**	0.078
	South Africa	-10.165**	-10.422**	0.151
International Reserves	Brazil	-2.167	-2.435	0.406**
	China	-2.261	-2.498	0.413**
	India	-2.859	-1.001	0.141
	Russia	-2.770	-2.643	0.276 **
	South Africa	-2.750	-2.986*	0.401**
Oil Price		-2.764	-2.544	0.227**

Notes: * and ** mean rejection of the null hypothesis at 5% and 1% respectively
ADF, PP and DF-GLS: H_0 - unit root; KPSS: H_0 - stationarity

We begin our empirical investigation by running basic ARDL estimations for the models related to equations 1 and 2. The variable ordering for the exchange rate determination model is: exchange rate, M3, inflation, interest rate, relative industrial production and international reserves. The ordering for the passthrough model is: CPI, exchange rate, industrial production and oil price.

The initial empirical exercise is to decide the number of lags needed to avoid autocorrelation in the estimation. Akaike Information Criterion is used as a first tool to help make this decision. The "lag number" column, in Table 2 reports these results and shows some differences and similarities amongst the BRICS countries. The ARDL estimated models (Table 2) reveals that, for the exchange rate dynamics model, lagged exchange rate and M3 are significant for all five countries, while lagged international reserves are also significant, except for China. Inflation, and industrial production are not relevant for Brazil and China, and interest rate does not play a role for Brazil and India. As for the passthrough model, all lagged dependent and explanatory variables are significant for Brazil and South Africa. For India, only lagged CPI is significant. In the Chinese case, lagged exchange rate is not significant and oil price does not play a role for Russia.

To make sure that the use of selection criteria was able to eliminate any autocorrelation problem, we ran some conventional autocorrelation LM tests. Table 2 also reports these results and shows no signs of autocorrelation in all estimated models. As for parameter stability diagnostic tests, our CUSUM and CUSUM Squared test results (Table 2 and Appendix) show that all estimated models are stable, except for Russia (CUSUM Squared) and China (CUSUM), both for the passthrough model.

Table 2: ARDL Bounds Testing Approach – Lags and Diagnostic Tests

	Exchange Rate Determination Model				**Passthrough Model**			
	Lag Number ARDL Model	**Autocorr. LM Test**	**Stability Tests**		**Lag Number ARDL Model**	**Autocorr. LM Test**	**Stability Tests**	
		Coeffic. [Prob]	**CUSUM**	**CUSUMSq**		**Coeffic. [Prob]**	**CUSUM**	**CUSUMSq**
Brazil	(3,3,0,0,0,3)[3]	1,642 [0.196]	Stable	Stable	(5,6,6,2)[2]	0,232 [0.792]	Stable	Stable
Russia	(3,3,0,5,7,3)[1]	1,094 [0.337]	Stable	Stable	(6,5,4,0)[3]	0,982 [0.376]	Stable	Instable
India	(3,1,2,0,5,6)[1]	1,473 [0.232]	Stable	Stable	(2,0,0,0)[3]	0,295 [0.744]	Stable	Stable
China	(4,1,0,2,0,0)[1]	1,279 [0.280]	Stable	Stable	(2,0,1,3)[1]	0,321 [0.725]	Instable	Stable
S. Africa	(6,6,0,2,0,6)[1]	0,905 [0.406]	Stable	Stable	(2,4,2,4)[3]	0,699 [0.498]	Stable	Stable

Note: 1 = with constant and trend; 2 = with constant and no trend; 3 = no constant. no trend.
Autocorrelation LM Test: (H_0 - no autocorrelation)

Table 3: Cointegration Test (ARDL-Bounds Testing Approach)

Country	**Exchange Rate Determination Model**					**Passthrough Model**				
	F-Statistics	**Critical Values**				**F-Statistics**	**Critical Values**			
		I(0) Bound		**I(1) Bound**			**I(0) Bound**		**I(1) Bound**	
		10%	**5%**	**10%**	**5%**		**10%**	**5%**	**10%**	**5%**
Brazil	9.376*	1,81	2,14	2,93	3,34	9.240*	2,37	2,79	3,2	3,67
Russia	4.775*	2,49	2,81	3,38	3,76	9.319*	2,01	2,45	3,1	3,63
India	5.777*	2,49	2,81	3,38	3,76	12.474*	2,01	2,45	3,1	3,63
China	5.352*	2,49	2,81	3,38	3,76	4.520*	2,97	3,38	3,74	4,23
South Africa	7.236*	2,49	2,81	3,38	3,76	20.677*	2,01	2,45	3,1	3,63

Notes: H_0 (no long-run relationship). * means long run cointegration at 5%.

Table 3 reports the results for all estimations related to exchange rate dynamics and passthrough models. As the F-statistics for all estimated ARDL bounds tests are higher than the I(1) bound, at 5%, there is clear indication of rejection of the null hypothesis of no cointegration for all ten estimated models. It means that there is a long run relationship between the variables analyzed for each BRICS member and for both model types: exchange rate determination model passthrough model.

After confirming the long run relationship (cointegration) for all estimated models, the next step is to analyze the specific estimated coefficients for the long run (Tables 4 and 5) and for the short run (Table 6), together with the error correction (ECM) coefficient.

The long run estimated coefficients for the exchange rate determination models for each BRICS country (Table 4) reveal that Broad Money (M3) is statistically significant for Brazil, India and China, with negative coefficients. Inflation is statistically significant for Brazil, Russia and India with positive coefficients. The only two statistically significant coefficients for interest rate are related to the cases of Russia and India, with positive values, while for the remaining countries the coefficient is negative and not significant. Industrial production plays a significant long run role for the exchange rate in Brazil, India and China with negative coefficients for the first two countries and positive for China. In the long run, coefficients related to international reserves show no statistical significance for all five BRICS countries.

Table 4: ARDL Long Run Coefficients (Exchange Rate Determination Model)

Country (Lags)	Brazil (3,3,0,0,0,3)	Russia (3,3,0,5,7,3)	India (3,1,2,0,5,6)	China (4,1,0,2,0,0)	S. Africa (6,6,0,2,0,6)
	Coeffic. (Prob.)	**Coeffic. (Prob.)**	**Coeffic. (Prob.)**	**Coeffic. (Prob.)**	**Coeffic. (Prob.)**
M3	-0.512** (0.004)	-0.194 (0.537)	-0.273* (0.001)	-0.252* (0.022)	-0.322 (0.270)
Inflation	0.241* (0.081)	0.129** (0.093)	0.031* (0.005)	-0.001 (0.741)	0.001 (0.978)
Interest Rate	-0.007 (0.586)	0.019** (0.058)	0.012* (0.002)	-0.006 (0.116)	-0.005 (0.757)
Relative Industrial Production	-1.148* (0.075)	-0.750 (0.676)	-0.563* (0.002)	0.246* (0.007)	0.020 (0.974)
International Reserves	2.16E-07 (0.610)	-1.36E-06 (0.169)	3.53E-07 (0.364)	-3.63E-08 (0.151)	-2.52E-05 (0.101)
Trend		0.005* (0.000)	0.004* (0.000)	0.001* (0.004)	0.005* (0.016)

Note: * and ** means significant at 5% and 10% respectively.

Table 5 reports the results for the long run coefficients of the passthrough model. The exchange rate is significant for China and South Africa but with negative and positive signs, respectively. If we consider only the magnitude (exchange rate elasticity) of the estimated coefficients related to prices, Brazil, Russia and India's prices are elastic relative to exchange rate, while China and South Africa show inelastic prices. Industrial production and oil prices are statistically significant only for South Africa, with positive and inelastic coefficients.

Regarding the non-expected negative sign for the Chinese exchange rate coefficient, one possible explanation is that China has faced a significant pressure from U.S. and Europe to appreciate its currency due to increasing and recurrent trade surplus for China vis-à-vis the American and European case, which is not the case of other countries in Asia. Another possible explanation can be associated with higher levels of international reserves by China, which can lead to additional pressure for exchange rate appreciation.

The next step is to analyze the short run dynamics of each estimated model, focusing on the Error Correction Representation (ECM). In fact, this is another important characteristic of cointegration models. The ARDL bounds tests showed that there is long-run equilibrium in all estimated models, i.e., the variables cointegrate. If this is the case, any short run shock may cause some type of disequilibrium in the model, but there must be some kind of adjustment towards the long run. This adjustment is given by the ECM term, and it can be faster or slower, depending on specific features of each BRICS country-member.

Table 5: ARDL Long Run Coefficients (Passthrough Model)

Country (Lags)	Brazil (5, 6, 6, 2)	Russia (6, 5, 4, 0)	India (2, 0, 0, 0)	China (6, 0, 1, 3)	S. Africa (2, 4, 2, 4)
	Coeffic. (Prob.)	**Coeffic. (Prob.)**	**Coeffic. (Prob.)**	**Coeffic. (Prob.)**	**Coeffic. (Prob.)**
Exchange Rate	3,18 (0.118)	-1.047 (0.723)	-2.096 (0.837)	-0.153* (0.009)	0.877* (0.000)
Industrial Production	20,01 (0.259)	2.722 (0.516)	1.450 (0.764)	0.374 (0.107)	0.341* (0.000)
Oil Price	-1,661 (0.366)	-0.682 (0.689)	2.376 (0.806)	0.020 (0.115)	0.331* (0.000)
Trend	-79,779 (0.272)			0.002** (0.000)	

Note: * and ** means significant at 5% and 10% respectively

These short run results are reported in Table 6 for the exchange rate determination and passthrough models, together with the estimated coefficients for the M3 variable, for the exchange rate dynamics models. This specific analysis is important to search for evidence of Dornbusch's phenomenon. As expected, all estimated lagged error correction terms (ECM_{t-1}) are negative and statistically significant. It means that, whenever a short run shock occurs, there is a slow speed of adjustment towards the long run equilibrium, for both exchange rate and prices. On average, 8.6% e 3.1% of the short run shocks are corrected within a month's time, for the exchange rate determination and passthrough models, respectively.

Table 6: Short Run Dynamics - Error Correction Representation (ECM)

	Exchange Rate Determination Model		**Passthrough Model**
	ECM(-1) [Prob]	**Δ(M3) [Prob]**	**ECM(-1) [Prob]**
Brazil	-0.016 [0.000]	-0.922 [0.000]	-0.001 [0.000]
Russia	-0.064 [0.000]	-0.796 [0.000]	-0.002 [0.000]
India	-0.179 [0.000]	-0.205 [0.000]	-0.001 [0.000]
China	-0.115 [0.000]	-0.475 [0.000]	-0.136 [0.000]
South Africa	-0.054 [0.000]	-0.867 [0.000]	-0.013 [0.000]
Average	-0.086	-0.653	-0.031

However, there is a significant discrepancy among the coefficients. In the case of exchange rate determination models, the coefficients vary from -0.016 (Brazil) to -0.179 (India), suggesting that convergence to equilibrium is faster for India than Brazil. For the passthrough model there is less discrepancy among countries, except for China (-0.136) with faster convergence. If we consider the passthrough in absolute value, the average is 1.47 indicating that for a 10% change in the exchange rate, prices will change by 14.7% in average for the BRICS countries.

Focusing on the estimated coefficients for M3 variable, our measure of broad money, they are all negative and statistically significant, in first difference, ranging from -0.205, in the Indian case, to -0.922, for the Brazilian case. This is an indication of lack of evidence of exchange rate overshooting on the grounds predicted by Dornbusch (1976). One possible explanation for the result of no exchange rate overshooting can be addressed by examining the coefficients of international reserves, in first difference, for the short run dynamics. The estimated coefficients are negative, meaning that increase (decrease) in international reserves are associated to exchange rate appreciation (depreciation), for three out of four estimated models (Brazil, India and South Africa). For the Chinese case (ARDL 4, 1, 0, 2, 0, 0) there is no "changes in international reserves" coefficient, for the short run ECM estimation. The majority of negative estimated coefficients for international reserves, in first difference, corroborates our suspicion that higher levels of international reserves accumulated by the BRICS countries, since 2005, can be, at least partially, a possible explanation for no exchange rate overshooting.

Conclusion

This article main goal was to investigate issues related to exchange rate dynamics and passthrough in the BRICS countries for the period ranging from January 2005 to December 2019 and using an ARDL Bounds Testing Approach to Cointegration methodology. One of the motivations of this research was to better understand phenomena related to exchange rate determination, including Dornbusch's overshooting in a different world economy and for a set of emerging economies. The BRICS countries faced periods of favorable terms of trade and accumulation of international reserves, as a general trend, helping curb severe volatility in foreign currency. Other than this, most countries adopted expansionary monetary and fiscal policies, especially after the 2007-08 financial crisis, but these actions did not lead to increasing inflation. This can be considered as an indication that the monetary transmission mechanism did not have its expected impact on prices, even after a significant number of years.

A second motivation for the paper was associated with the investigation of the exchange rate passthrough for the BRICS. The argument was that, in a more globalized world environment, exchange rate movements are more likely to have an impact on domestic prices, which could affect inflation rates.

The results of our estimated models showed a clear long run (cointegration) relationship in all estimated models. The long run estimated coefficients for the exchange rate dynamics models revealed that our broad money measure (M3), was statistically significant for Brazil, India and China, with negative coefficients, and inflation was statistically significant for Brazil, Russia and India, with positive coefficients. On the other hand, there was no statistical significance for international reserves, for all five BRICS countries. The short run dynamics showed a slow speed of adjustment towards the long run equilibrium, for the exchange rate determination model, with an average of 8.6%. The short run estimated coefficients for M3 were all negative and significant, showing lack of evidence related to exchange rate overshooting.

As for the results passthrough model, the long run coefficients for the exchange rate are statistically significant only for the Chinese and South African cases. Industrial production and oil price are statistically significant only for South Africa. Overall, if we consider the exchange rate passthrough in absolute value, the average is 1.47 indicating that for a 10% change in the exchange rate, prices will change by 14.7% in average. As for short run dynamics, there was also a slow speed of adjustment towards the long run equilibrium, as in the exchange rate determination model, with an average of 3.1%. It means that there is evidence of exchange rate passthrough, but not so strong as before.

If one has to address this result it is necessary to keep in mind that the world economy is quite different from the period after Bretton Woods. The adoption of flexible exchange rates by advanced economies in the mid of 1970s and the rising of BRICS as emerging economies with different macroeconomic characteristics, makes difficult to compare them with advanced economies four decades ago. The role of monetary policy and its transmission mechanisms has also changed substantially during this period, meaning that its impact on prices, including the exchange rate, has also changed.

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Appendix

Figure 1 A: Stability Tests (CUSUM and CUSUMSq) Exchange Rate Dynamics Model

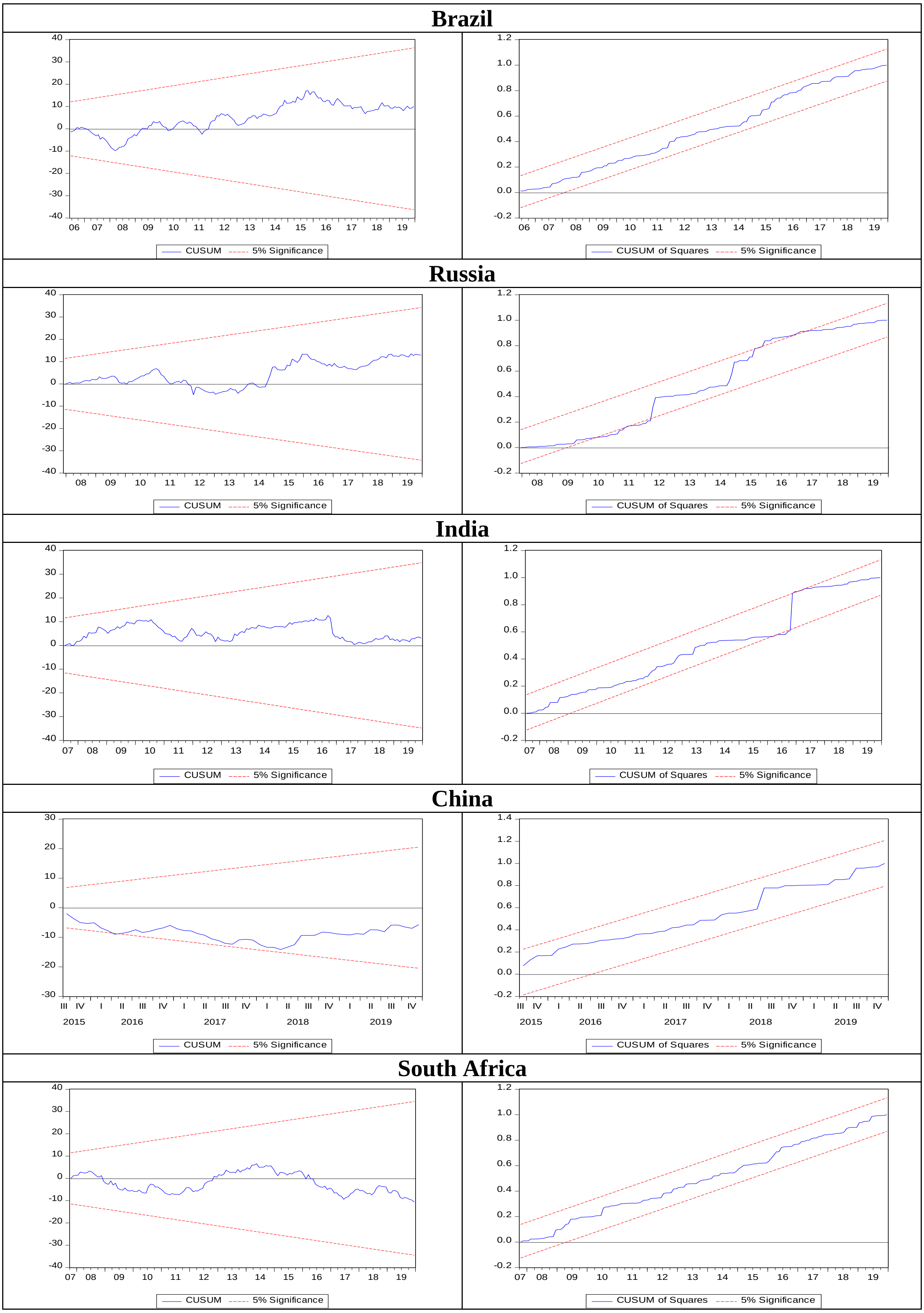
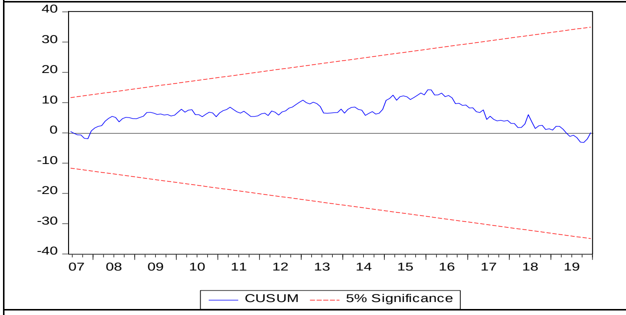
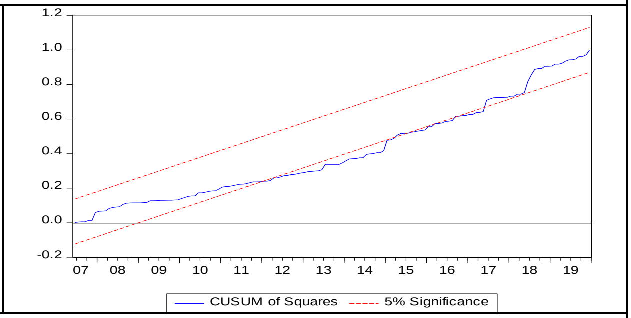


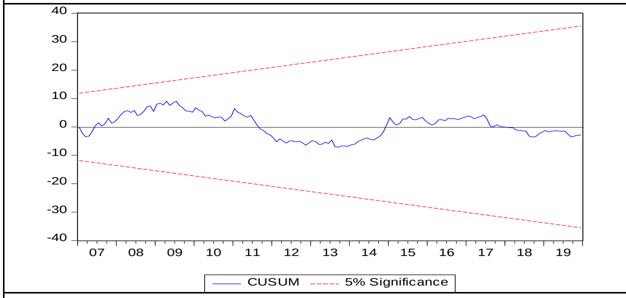
Figure 2A: Stability Tests (CUSUM and CUSUMSq) Passthrough Model

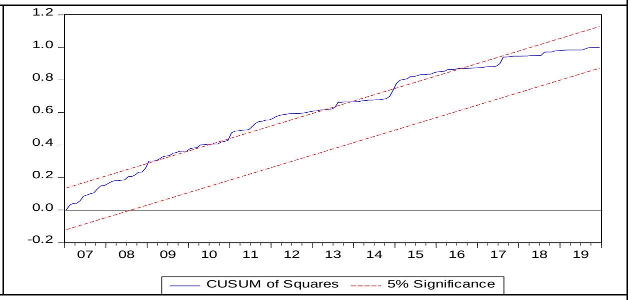
Brazil



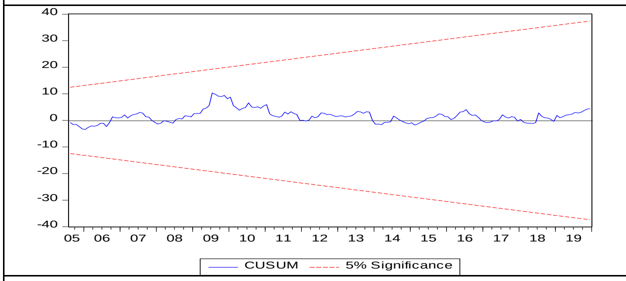


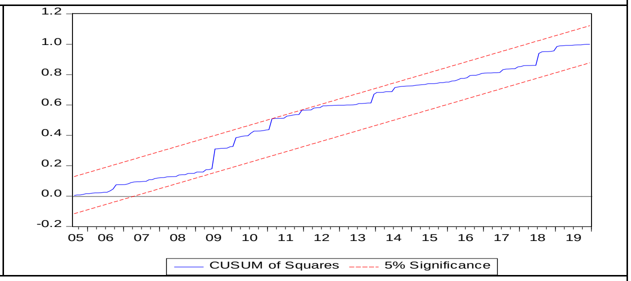
Russia



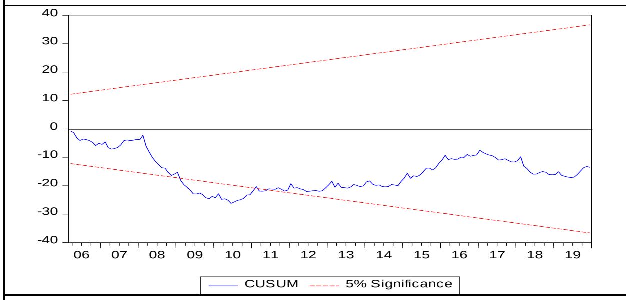


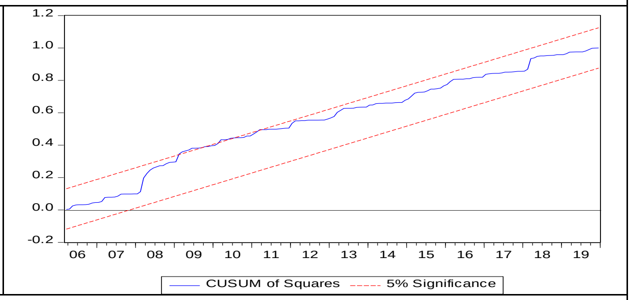
India





China





South Africa