ESSAYS ON EXCHANGE RATE VOLATILITY IN BRICS ECONOMIES

DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ECONOMICS OF JADAVPUR UNIVERSITY, KOLKATA

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Certified that the Thesis entitled ***Essays on Exchange Rate Volatility in BRICS Economies*** submitted by me for the award of the Degree of Doctor of Philosophy in Arts at Jadavpur University is based upon my work carried out under the supervision of Dr. Saikat Sinha Roy, Professor, Department of Economics, Jadavpur University, Kolkata, and neither this thesis nor any part of it has been submitted before for any degree or diploma anywhere/elsewhere.

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CHAPTER 1

Overview

1.1 INTRODUCTION

This thesis is a collection of essays investigating into various aspects of exchange rate volatility in BRICS[1] economies during the period 2006 to 2018.[2] With structural changes in the global economy, the share of developing economies, especially emerging market economies (EME's), in world GDP, trade, capital inflows, stock market capitalization, and foreign exchange market turnover[3] have increased over time. Among these EME's, the BRICS countries assume a predominant position.[4] Despite emerging strong globally, volatility in currency markets is a possibility with these countries getting more financially integrated and adopting a regime of more flexible exchange rates.

Over the decades, emerging market economies (EME's) have moved from a fixed towards a more floating exchange rate regime. With increasing flexibility, volatility in foreign currency markets has increased manifold (Kocenda & Valachy, 2006). Apart from the adoption of a floating exchange rate regime, exchange rate volatility is a result

[1] BRICS stands for an association of five emerging market economies, namely Brazil, Russia, India, China and South Africa.

[2] The initial year in the study is chosen to be 2006 on account of the following reasons. First, the formation of BRICS as a regional group was initiated with the first meeting of the leaders of the four countries namely Brazil, Russia, India, and China in September 2006 on the sidelines of the General Debate of the UN General Assembly to enhance development cooperation among these countries. Later on, in April 2011, South Africa is included in the regional group. Originally the term BRIC, except South Africa, was first coined by Goldman Sachs (O'Neill, 2001). Second, China abandoned the pegged exchange rate system for a managed float exchange rate regime with reference to a basket of currencies from July 2005.

[3] Global turnover in foreign exchange market in the recent period is higher than earlier, which is on account of international trade as well as speculation and market trading activities (BIS, 2016).

[4] According to IMF, World Economic Outlook Database, April 2021, among the BRICS countries, four are in the top ten economies in the world in terms of the purchasing power parity adjusted nominal gross domestic product. The rank of the top four BRICS countries are as follows: China (rank 1), India (rank 3), Russia (rank 6) and Brazil (rank 8). Initially it was stated that these economies together could be larger than the G-6 countries in terms US Dollar by 2050 (Wilson & Purushothaman, 2003; Cheng et al. 2007).

of pattern of trade, government debt, speculative activities of the investors and policy makers, global imbalances, economic and financial crises, and political instability, among others. Economic crises in recent decades have often led to increase in exchange rate volatility in EME's. In addition, the announcement by FED to end quantitative easing led to large currency depreciation in the emerging market economies.

In general, exchange rate is a key macro-financial variable, and exchange rate volatility is found to affect many macroeconomic variables. A rise in real exchange rate volatility can have detrimental impact on the economy through its adverse consequences on private agents' consumption and investment (Arezki et al. 2014).[5] Obstfeld & Rogoff (1998) discuss direct and indirect channels through which exchange rate volatility negatively affects households and firms. The direct channel asserts that exchange rate volatility will impact on households and firms as it will have undesirable impact on their consumption and leisure decisions. A rise in exchange rate volatility will cause fall in exports, the production and income at home as well as foreign country, and eventually aggregate consumption will decline. On the other hand, aggregate consumption declines indirectly as an increase in exchange rate volatility compels the firms to hedge the risk of future exchange rate volatilities and thus may set higher prices or charge a higher risk premium. Further, if small firms find it difficult to hedge against rising exchange rate volatility, it may adversely affect export performance (Raddatz, 2011; Arezki et al. 2014).

Volatility in exchange rate can also adversely affect any emerging markets by changing the international price of goods or assets. High volatility in the foreign exchange market can also pose downside risks to competitiveness of exports,

[5] It affects economic decision making. For instance, Evans & Lewis (1995) show that exchange rate switches are incorporated into rational traders' forecasts of the future exchange rate.

international investment portfolio, international reserves and currency value of debt payments in particular and more generally on the overall stability of the economy (Annachhatre, 2013). An increase in exchange rate volatility also increases inflation expectations and interest rate which adversely affects production, consumption, domestic investment activity and economic growth of a country.[6] Exchange rate volatility affects the returns of financial and capital markets expressed in domestic currency, and also makes investment in these markets susceptible to foreign exchange risks. A large depreciation also leads to worsening of external debt liabilities as most of these economies issue their debt in terms of foreign currencies. A widening current account deficit results in deteriorating a country's net international investment position (NIIP) by increasing the international liabilities as compared to international assets. This change in the NIIP is on account of a change in valuation originating from the variation in exchange rates and in the prices of financial instruments which comprise of a country's assets and liabilities, in particular. Exchange rate volatility, thus, adversely affects the real economy's performance by influencing net capital flows, net international trade and growth along with causing instability in the financial sector.

The central bank intervenes[7] to stabilise the currency whenever it shows unusual movements on account of some shocks originating at home or abroad. For instance, earlier the Bretton Woods system was introduced to contain the exchange rate volatility,

[6] See Darby et al. (1999), Schnabl (2008), Vieira et al. (2013), Jamil et al. (2012), Rjoub (2012), Janus & Riera-Crichton (2015), Allen et al. (2016), Alagidede & Ibrahim (2017), Dal Bianco & Loan (2017), Latief & Lefen (2018), Vo & Zhang (2019), Hatmanu et al. (2020), Ioan et al. (2020) on the effect of exchange rate volatility on trade, investment and economic growth. Morina et al. (2020) opine that real exchange rate volatility negatively affects the exchange rate.

[7] One of the most influential papers of the genre of literature on exchange rate management is Krugman (1991). While presenting a model of exchange rate behaviour in a permanent target zone, Krugman (1991) advocates that the monetary authorities intervene in foreign exchange markets when the spot rate touches the defined currency band. Interestingly, even if the authorities have not intervened at all, the mere decision to intervene automatically corrects the exchange rate within the specified currency band.

which was abandoned later on in 1970. The European countries adopted the Exchange Rate Mechanism in 1980 aiming at strengthening cooperation among the European nations to reduce the exchange rate variability. One of the main reasons behind the formation of the European Monetary Union at a later date was to deal with the irregularity in the foreign exchange market. Any central bank, irrespective of that in a developed or an emerging market economy, intervenes to counter exchange rate volatility (Dooley, 2000; Chang & Velasco, 1998 and Cespedes et al., 2004).[8] However, in majority of the occasions, such interventions in the foreign exchange market were only partially successful.[9]

One of the most relevant questions is whether nominal or real exchange rate volatility is to be considered in the study, while a number of studies show that both types of volatility are closed linked to each other (Rigobon, 2008). Any fluctuation in the nominal exchange rate is being transmitted automatically to real exchange rate and any intervention conducted to stabilise the nominal exchange rate also stabilises the real exchange rate.[10] With the adoption of a flexible from a fixed exchange rate regime, the deviations of both nominal and real exchange rates are found to increase in the short run.[11] Such deviations, according to Rigobon (2008), are on account of factors affecting nominal and real exchange rates, which are in addition to short run sticky prices[12] or

[8] However, many emerging market economies adopted the fixed exchange rate regime from crawling pegs in response to crises such as the Mexican crisis in 1994-95, the Asian crisis in 1997-98, the Brazilian crisis in 1999 and the Argentinean crisis in 2001, among others (Fiess & Shankar, 2009).
[9] Instances of partial success often lead countries to target inflation instead of exchange rate stabilisation (Rigobon, 2008), however the global imbalances debate points to the latter having the edge over the former.
[10] Mussa (1986) views that nominal and real exchange rates move in similar ways.
[11] This short-run volatility continues in the long run in terms of deviation in real exchange rate.
[12] Several studies empirically document varying degrees of short run price stickiness, which in turn implies short-run variations in nominal as well as the real exchange rate. Studies, for instance, Bils & Klenow (2004), Alvarez et al. (2006), and Gopinath & Rigobon (2008), show varying degrees of price stickiness across countries.

demand shocks governing short run fluctuations in nominal exchange rate. The variations in nominal and real exchange rates in the short run follow a cyclical order where stabilising the nominal will result in real exchange rate stability.[13]

The Context

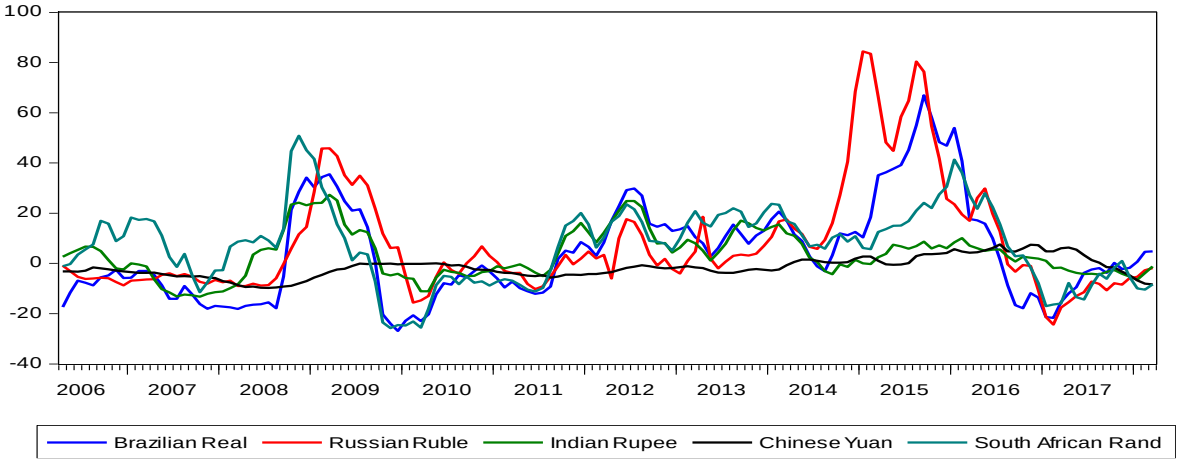
The BRICS, as a group accounts for 28.3 per cent of the global output in 2018 as against 11.8 per cent in 2006.[14] The total trade of BRICS has more than doubled from US$ 2.7 trillion in 2006 to US$ 6.6 trillion in 2018 with total exports of BRICS doubling from US$ 1.6 trillion to US$ 3.5 trillion resulting in an increase in the share of BRICS in global exports during the period. As a result, the share of BRICS in global trade has also increased from 12.7 per cent in 2006 to 18.2 per cent in 2018. Trade surplus of the BRICS countries also increased from US$ 375.8 billion in 2006 to US$ 457.1 billion in 2018. Besides, the BRICS countries experienced a staggering growth in the flow of FDI with the share of these countries in world FDI increasing from 9.2 per cent to 33.3 per cent between 2006 and 2018. Foreign exchange reserves, for the BRICS as a whole, increased during this period from US$ 1347.99 billion to US$ 4364.39 billion. This improving economic prospect of the BRICS countries attracted investors and portfolio managers with their increasing participation in the foreign exchange markets of BRICS countries. According to the Bank for International Settlements (BIS) Triennial Central Bank Survey (2019), the foreign exchange market turnover was US$71 billion for Brazil, US$72 billion for Russia, US$113 billion for India, US$284 billion for China and US$72

[13] Rogoff (1996) assumes that purchasing power parity holds in the long run and that the average half-life of real exchange rate deviations from trend is around three to four years. In contrast, Imbs et al. (2005) find that, at the sectoral level, the mean reversion is even stronger with half-lives of around a year.
[14] The nominal GDP of BRICS economies is projected at US$ 23 trillion with an expected increase in share of about 25.2 per cent in world GDP by 2020 (Export Import Bank of India, 2016).

billion for South Africa respectively, thereby accounting for 9.3 per cent of the global foreign exchange turnover in April 2019.

With the advent of the floating exchange rate regime, currency volatility in emerging markets increased in a significant way. BRICS is also no exception to this pattern. It can also observed from Figure 1.1, the exchange rates of BRICS currencies with respect to the US$ fluctuated during the period since 2006. The variance in the currencies is 0.000110, 0.000083, 0.000021, 0.000002 and 0.000124 for Brazil, Russia, India, China and South Africa respectively during 2006 to 2018. Moreover, as can be observed from Figure 1.2, with the BRICS economies getting increasingly integrated with world financial market, volatility in currency market returns got higher than before, in particular after the global financial crises.

Figure 1.1: Y-o-Y percentage change of the monthly exchange rate of BRICS



The extent and persistence of such currency market volatility also adversely affects, directly or indirectly, a number of key policy variables, including interest rate, returns on investment and, hence growth, directly or indirectly getting affected. Any

misalignment in the exchange rate to this extent requires intervention in the respective foreign exchange market through appropriate exchange rate policy along with other policies. Managing currency volatility is thus a major policy challenge for individual central banks while formulating monetary policy in emerging market economies, including the BRICS economies.

The respective central bank in these economies has intervened in the respective currency markets to check excess volatility through purchase and sale of foreign currencies. For instance, the Central Bank of Brazil, Russia, India and South Africa conducted the sale of foreign exchange during the global financial crisis in 2008. According to Federal Reserve Bank of St. Louis database, the foreign exchange reserves fell for Brazil from US$ 205.54 billion in September 2008 to US$ 187.11 billion in January 2009, from US$ 542.84 billion in September 2008 to US$ 371.43 billion in January 2009 for Russian Ruble, from US$ 277.77 billion in September 2008 to US$ 239.68 billion in January 2009 for India, and from US$ 30.83 billion in September 2008 to US$ 30.01 billion in January 2009 for South Africa, which is indicate sale of foreign exchange reserves. On the other hand, China purchased foreign exchange between September 2008 and January 2009, with the reserves increasing from US$ 1907.73 billion to US$ 1916.57 billion during the period.

The BRICS, as a emerging market bloc, also set up a Contingency Reserve Arrangement in 2015 to guard against any short run eventuality in the balance of payments and hence, exchange rate volatility. Aizenman (2013) shows that with greater financial globalization among the countries, there is a greater possibility of exposure to financial turbulences to which the emerging market economies respond by hoarding

foreign exchange reserves as a means of self insurance.[15] In short run, this hoarding of reserves will guard against financial instability and will allow pursuing independent macroeconomic policies.

The delineation of the above basic facts on exchange rate volatility in BRICS countries builds a strong case for a detailed study on certain aspects on such dynamics. Prior to embarking on a path to unravel the dynamics in currency volatility, it is important to lay the foundation of analysis with theoretical underpinnings on exchange rate volatility.

1.2 EXCHANGE RATE VOLATILITY: SOME THEORETICAL UNDERPINNINGS

Exchange rate volatility is traditionally associated with changes in exchange rate regime from a fixed to a free floating one. Later on, with globalization since the early 1990s, volatility in the global economy has increased manifold. The currency market is no exception. The BOP crisis of the late 1990s, unpredictable capital flows in the emerging market economies or speculative stock and financial markets gave rise to exchange rate volatility. The perception of volatility in the foreign exchange market has widened over time and has emerged into an independent field of inquiry.

[15] This self insurance motive was more prevalent among the emerging market economies rather than developed economies which have alternative channels such as bilateral swap lines or ability for external borrowings to deal with the crises. The international reserves/GDP ratio of industrial economies was merely 4 per cent in 1980 whereas the same for developing countries rose from 5 to 27 per cent during 1980-2006. Aizenman & Lee (2007) elaborated that the self insurance motive along with increasing exposure of sudden-stops and deleveraging crisis primarily contributed to the growing international reserves in emerging economies in 1990s. By 2007, the developing economies almost hold two-third of the global international reserves, with Asia emerging as the major hub of hoarded foreign exchange reserves. For instance, the international reserves/GDP ratio of Asian economies grew from 5 to 37 per cent during 1980-2006. Among the Asian economies, China's international reserves/GDP ratio alone grew from 1 per cent in 1980 to 41 per cent in 2006 (Aizenman, 2013). This tendency increased particularly after the East Asian Crisis in 1997-98 because it severely affected the high saving countries with balanced fiscal accounts (Aizenman & Marion, 2003).

Conceptually, volatility can be decomposed into predictable and unobserved components. Even though, it is an arduous task to make a distinction among volatility, uncertainty, risk, variability, fluctuation or oscillation. According to Knight (1921), volatility is related to risk in that it provides a measure of the possible variation or movement in a particular economic variable or some function of that variable over some historical period. Volatility essentially includes variability and uncertainty - variability in an economic variable may be anticipated while the residual which captures pure risk or uncertainty is unanticipated and constitutes a 'shock'. The size and persistence of such shocks can pose a major challenge as it can evolve into extreme volatility or a crisis.

Volatility in exchange rate can be explained in terms of three possible factors - volatility in market fundamentals, changes in expectations due to new information and speculative "bandwagons" (Engel & Hakkio, 1993). Volatility in market fundamentals such as the money supply, income and interest rates affects volatility in exchange rate. Changes in expectations about future market fundamentals or economic policies also affect exchange rate volatility as new information induces the market participants to alter their forecasts of future economic conditions and policies thereby leading to exchange rate volatility. Exchange rate can also be volatile on account of speculative bandwagons or speculations unrelated to current or expected market fundamentals. If speculators buy dollars on the assumption that dollar will appreciate, but if it becomes apparent that market fundamentals will not sustain such an appreciation, then it can result in selling of dollars which could cause the dollar to depreciate. Such behaviour on the part of the speculator can cause the value of the dollar to fluctuate thereby contributing to exchange rate volatility.

Following the collapse of the Bretton Woods system in 1973, the member countries were free to choose any exchange rate arrangements except pegging their currency to gold. These countries can link the value of their currency to another country's currency, to a basket of currencies or adopt a floating exchange rate system, thereby allowing the market forces to determine the value of the currency relative to other currencies. Consequently, many leading and the emerging economies adopted the floating (managed or dirty or free) exchange rate system which resulted in the exchange rate volatility.[16] To explain such evidence of exchange rate volatility, a large body of theoretical literature emerged.

As shown in the literature, fundamentals play a critical role in determining the exchange rate volatility. For instance, Driskill & McCafferty (1980) study an exchange rate model in a small open economy with uncertainty and flexible exchange rate. Assuming rational expectations, it is argued that high capital mobility increases the portfolio variability on account of changes in anticipated relative asset yields and decreases(increases) the exchange rate volatility following real shocks(monetary shocks). Turnovsky & Bhandari (1982) extend the Driskill & McCafferty (1980) analysis by incorporating the real sector and analyse the short-run effects of structural shocks of domestic and foreign variables on domestic economy. The study advocates that shocks in foreign price level and foreign interest rate along with increased capital mobility increase

[16] There is another strand of literature which says that exchange rate does not depend on fundamentals. For example, Meese & Rogoff (1983) argue that present day exchange rate is mostly determined by previous day's exchange rate indicating path dependence and show that the random walk model outperforms most of the exchange rate model in the short-run. On the contrary, exchange rate model outperforms random walk models in medium to long-run (Chin & Messe, 1995). Nonetheless, Evans & Lyons (2002) show that order flows contribute almost 70 percent of the variability in nominal exchange rate in short-run. Apart from this, exchange rates in small open economies are mainly influenced by fundamentals of other countries via trade linkages, financial linkages or through crises or contagion (Forbes & Rigobon, 2001, 2002; Kaminsky et al., 2003 and Pavlova & Rigobon, 2007, 2008).

exchange rate volatility while domestic supply shocks have a negative effect on the volatility in exchange rate.[17] These theoretical explanations offered by Dornbusch (1976), Frenkel (1976), Kouri (1976) and Mussa (1976), as survey by Flood (1981) shows, differ from the exchange-market fundamentals based explanations of exchange rate volatility.

Driskill & McCafferty (1987) extend their previous (1980) work by including the assumption of risk-aversion and derivation of asset demand equation from optimizing behavior and show that the variance of money supply shocks positively affects the volatility in exchange rate and changes in preferences and technology confirm the existence of multiple equilibria. Grydaki & Fountas (2009) show that money supply volatility, government spending volatility along with covariance of money supply and government spending shocks have a positive impact on exchange rate volatility. In same line, Grydaki & Fountas (2010) show that variations in money supply, inflation, output variations and financial openness affect the exchange rate volatility. Morana (2009) further shows long term linkages and trade off between volatility in exchange rate and output volatility, money growth volatility and inflation volatility with the direction of causality much stronger from the volatility in these macroeconomic variables to the volatility in exchange rate.[18]

Betts & Devereux (1996) show that the pricing-to-market model impacts the exchange rate volatility and the magnitude of variability in exchange rate may increase in the economy in the absence law of one price. Moreover flexible exchange rate regimes

[17] However, Manuelli & Peck (1990), using an overlapping-generations model with stochastic endowments provide evidence that fundamentals do not affect exchange rate volatility, but shocks to these fundamentals significantly affect volatility in exchange rate.

[18] However, Flood & Rose (1995) find no link between macroeconomic fundamentals and exchange rate volatility.

tend to increase exchange rate volatility. Stancik (2006) show that openness, news and exchange rate regimes contribute to the exchange rate volatility in EU member countries.[19] Bayoumi & Eichengreen (1998) show that the effect of optimum currency area (OCA) variables such as trade dependence, capital controls and money supply reduce exchange rate volatility. Similarly, Devereux & Lane (2003) shows that external debt negatively affects the bilateral exchange rate volatility in developing countries whereas OCA variables are more important, in comparison to external debt, in influencing the volatility in exchange rate in case of industrial countries.

Canales-Kriljenko & Habermeier (2004) show that factors such as inflation, real GDP growth, fiscal deficit, and trade openness affects the volatility in exchange rate whereas current account deficit, private capital flows relative to GDP and volatility in terms of trade does not have a significant affect the exchange rate volatility. Karras (2006) show that trade openness, as a single dependent variable, positively affect the exchange rate volatility,[20] but when economic size is introduced in the model, both trade openness and economic size is negatively related to exchange rate variability.[21] Mpofu (2020) claims that trade openness reduces the Rand real exchange rate volatility and the interaction of trade openness and exchange rate regime dummy has a negative effect on the real exchange rate volatility. Moreover the study also shows that the volatility of output, commodity prices, money supply, and the ratio of general government

[19] The effect of news on exchange rate volatility is also elaborated in Dornbusch (1979), Frenkel (1981), Galati & Ho (2003), Engle & Ng (1993) and Sanchez-Fung (2003). On the other hand, Reinhart & Rogoff (2002) argud that modelling the exchange rate regimes need much attention as their study reveals that majority of the official pegs are actually floats and vice-versa.

[20] Chipili (2012) also subscribes to the same view.

[21] Similar studies by Gali & Monacelli (1999) show that an increase in trade openness reduces exchange rate volatility, increases output volatility and has an ambiguous effect on consumption volatility whereas Hau (2002) presented an inverse relationship between trade openness and real exchange rate volatility (Amor & Sarkar, 2008; Bleaney, 2008; Calderon, 2004; Calderon & Kubota, 2018; Caporale et al. 2009).

consumption expenditure to GDP and exchange rate regime significantly influence the Rand volatility.[22] The above discussions shed light on the variables which causes on the exchange rate volatility.

There is a large literature focusing on cross-country volatility spillover between exchange rates in addition to cross-asset volatility spillover.[23] For instance, Hong (2001) proves the existence of granger causality between two weekly nominal US Dollar exchange rates with respect to Deutsche Mark and Japanese Yen. Sahoo (2012) shows volatility transmission from Brazilian Real, Russian Ruble, South Korean Won, Singapore Dollar, Japanese Yen, Swiss Franc, British Pound Sterling and the Euro to the exchange rate of the Indian Rupee. It is observed that cross-border volatility transmission, especially in financial markets, among nations is a possibility with economic links (Abbas et al. 2013; Ahmad et al. 2018; Chkili, 2016; Kocaarslan et al. 2017; Mensi et al. 2015; Syriopoulos, 2015; Mensi et al. 2016; Walid et al. 2011; Yarovaya & Lau, 2016;

[22] Alternatively, Krugman (1989) argues that weak response of international pricing and investment decisions to exchange rate movements generate excessive real exchange rate volatility.

[23] There is a large literature focusing on the relation between exchange rate volatility and that in other assets. For example, Bodart & Reding (1999) show that declining bond market volatility is associated with credible fixing of exchange rate. Moreover, an increase in exchange rate volatility will significantly lower the conditional correlation between bond markets with very less effect on the conditional correlation of stock markets. Blau (2018) shows that increase in exchange rate volatility of home country currency will increase the volatility in American Depositary Receipts (ADRs). The study further reports that the unexpected unpegging of Chinese Yuan in 2005 has considerably increased the volatility of Chinese ADRs. While some researchers find that exchange rate volatility can create excess volatility in asset prices, others show that variability in exchange rates can actually reduce asset price volatility (Artis & Taylor, 1994; Flood & Hodrick, 1986; Frenkel & Mussa, 1980; Flood & Rose, 1995; Henderson & McKibbin, 1993; Marston, 1985 and Rose, 1995). There is also a large literature on the volatility of exchange rate and its impacts on exports. Recent literature in this regard include Klein, (1990); Asseery & Peel, (1991); Arize, (1995); Doganlar, (2002); Sauer & Bohara, (2001); Chit, (2008); Chit et al. (2010); Obstfeld & Rogoff, (1998); Franke, (1991); Giovannini, (1988); Sercu & Vanhulle, (1989); Bahmani-Oskooee & Gelan, (2018); Senadza & Diaba, (2018); Alper, (2017); Bostan & Firtescu, (2019); Latief & Lefen, (2018); Bleaney & Greenaway, (2001); Bagella et al., (2005); De Grauwe & Schnabl, (2008); Aghion et al., (2009). Besides, there are studies exploring the relationship between exchange rate volatility and unemployment (Belke & Gros, 2002a,b; Belke, 2005; Belke & Gros, 2001 and Feldmann, 2011). Nonetheless, the increasing exchange rate volatility affects economic growth by disturbing its components individually. A rise in exchange rate volatility increases risk of domestic investment (Darby et al. 1999; Serven, 2003 and Byrne & Davis, 2005) and also has adverse impact on foreign direct investment (Campa, 1993; Urata & Kawai, 2000).

Zhang et al. 2013; and Gomez-Gonzalez et al. 2020; among others). Such studies include transmission of volatility to BRICS financial markets, including exchange rates.

It is thus important to study exchange rate volatility in BRICS countries from various perspectives. In understanding volatility dynamics in BRICS foreign exchange markets, a discussion on the behaviour of regime switching from appreciation to depreciation and vice versa in currencies is required. Moreover, the exchange market pressure (EMP) and the intervention index provide some insights into the pressure on individual BRICS currency to appreciate or depreciate and interventions by the respective central banks to contain such EMP. Further, an investigation to understand the extent of exchange rate return co-movement and direction of volatility spillover between BRICS currency markets and other currencies is important, given the degree of connectedness between these countries. Finally, exploring the factors that induce exchange rate volatility is imperative in arriving at appropriate policies for exchange rate management. One such important factor determining exchange rate volatility is economic policy uncertainty, which has important implications for foreign exchange market as policy uncertainties can cause turmoil in the exchange market thereby discouraging investors and portfolio managers to invest in other assets. It is not only important to examine the effect of own country Economic Policy Uncertainty, but also global economic policy uncertainty[24] on volatility of BRICS currencies. At this juncture, it is essential to develop a perspective on currency volatility in terms of changes in exchange rate policies in the BRICS countries, to which we turn now.

[24] In this study, US economic policy uncertainty (EPU) is taken to represent global uncertainty. It is also important to examine the impact of US EPU index on the volatility of BRICS currencies as the exchange rate of all BRICS currencies are with respect to US Dollars. So it is imperative that any policy uncertainty in the US may affect the foreign exchange market in individual BRICS economies.

1.3 BRICS EXCHANGE RATE: EVOLUTION AND POLICIES UNDERTAKEN

The BRICS currencies have gone through a number of policy changes towards reforms: from being fixed to a managed float to a free or back float or back in the past several decades. The adoption of different exchange rate regimes in BRICS economies over the period depended on prevailing economic condition as well as to cope with financial sector changes in the world economy. Table 1.1 shows the period-wise classification of exchange rate regimes of the BRICS countries by Ilzetzki, Reinhart & Rogoff (2016). It can be observed from the table that barring Brazilian Real and South African Rand, the exchange rate regime in most BRICS countries have evolved from a

Table 1.1: Exchange Rate Regimes: BRICS Countries

Country	Time Period	Exchange Rate Regime
Brazilian Real	2006M4 - 2008M9	Freely floating
	2008M10 - 2018M3	De facto moving band +/-5%/ Managed floating
Russian Ruble	2006M04 - 2008M8	De facto crawling peg
	2008M9 - 2012M12	De facto moving band +/-5%/ Managed floating
	2013M01 - 2014M10	De facto crawling band that is narrower than or equal to +/-5%
	2014M11 - 2016M2	Freely falling
	2016M3 - 2018M3	De facto crawling band that is narrower than or equal to +/-5%
Indian Rupee	2006M4 - 2009M2	De facto crawling band that is narrower than or equal to +/-2%
	2009M3 - 2012M11	De facto crawling band that is narrower than or equal to +/-5%
	2012M12 - 2018M3	De facto crawling band that is narrower than or equal to +/-2%
Chinese Yuan	2006M4 - 2014M11	Pre announced crawling peg; de facto moving band narrower than or equal to +/-1%
	2014M12 -2018M3	De facto crawling peg
South African Rand	2006M4 - 2018M3	Freely floating

Source: Based on Ilzetzki, Reinhart & Rogoff (2016)
Note: Ilzetzki, Reinhart & Rogoff (2016) has classified the exchange rate regimes upto December 2016. The study has then analysed the Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER) 2017 and 2018 which states that the BRICS countries has not change the exchange rate regime after December 2016 i.e they continued with the same exchange rate regime that was in December 2016. The authors have simply extended the exchange rate regime, which prevailed during December 2016, to March 2018.

managed float to a free floating regime during the period. The monetary authorities, at times, chose to fix their exchange rate against developed country currencies like Dollar, Pound Sterling or a basket of currencies or to float, managed or dirty, against the same. The central banks of the BRICS countries intervene regularly to maintain or to change the prevailing exchange rate regime depending on the existing market conditions or the macro factors influencing the exchange rate. The South African Rand was in a free floating regime during the period, while the Brazilian Real moved back to a managed float since October 2010 from a free floating regime. The choice of the regime by the authorities is primarily to stabilize the currency from excessive depreciation or appreciation. A brief description about the evolution of the exchange rate policy in BRICS countries is presented below.

Exchange rate policy of Central Bank of Brazil

In the early 1990s, the Central Bank of Brazil (BCB) followed a pattern of economic development based on crawling peg exchange rate regime with nominal devaluations that resulted in a depreciated real exchange rate and a policy of high real interest rates. Such policy generated high trade balance surplus and attracted capital flows but at the cost of a very high inflation. In July 1994, the Real Plan, characterized by a crawling exchange rate band, was launched through the implementation of a tight monetary policy in order to stabilize the domestic currency in nominal terms. Accordingly, a new unit of account, the Unit of Real Value (URV), pegged to the US dollar, was introduced. The URV, latter re-named as Real, began to operate as the new currency. Under the new exchange rate regime, the monetary authority committed itself to selling foreign exchange reserves once the price of the Real reached one US dollar, but

was not obliged to intervene when the Real was worth more than one dollar. The period 1994-1999 was marked by semi-fixed exchange rate regime as the Central Bank of Brazil (BCB) defined the nominal exchange rate inside a narrow band and the currency was not truly free, being more accurately described as a managed or dirty float with frequent central bank interventions to manipulate its dollar price.

The effects of the Real Plan on the real exchange rate, the external accounts and debt accumulation finally led to an exchange rate crisis in early 1999. After the crisis of 1999, the BCB has had no commitment to determine exchange rate, although it has operated occasionally in the foreign exchange markets in periods of higher volatility in international capital flows and, more recently, in accordance with its policy of accumulating foreign exchange reserves.

Exchange rate policy of The Central Bank of Russian Federation

After the collapse of the Soviet Union in 1991, the Russian Federation was economically and financially unstable with prevailing hyperinflation during 1992-94 and high inflation during 1995-98. As a consequence, The Central Bank of Russian Federation (also known as Bank of Russia) adopted a monetary policy primarily focused on exchange rate and introduced an exchange rate corridor system[25] in 1995 aimed at strengthening the Ruble, which may also act as a nominal policy anchor. Following the government debt crisis in 1998, the managed float exchange rate system was adopted by the central bank and exchange rate became dependent on market fundamentals. The central bank continued to effectively manage the exchange rate which helped built up confidence in the country's financial system.

[25] It mainly refers to the creation of an upper and lower limit of exchange rate adjustments with regular alteration by the monetary authorities. This was enacted by the Central Bank to prevent the depreciation of the currency and stabilize it.

In 2004, capital controls were liberalised which resulted in appreciation of the Ruble. This was followed by central bank intervention to maintain the competitiveness of exports and financial stability of the country. In order to further reduce the volatility of Ruble against major currencies, the Bank of Russia introduced a dual-currency basket in 2005, consisting of US dollar and Euro with unequal shares. The value of the basket, which remained relatively stable during 2005-08, was designed in such a manner that it will change in accordance with the change in nominal effective exchange rate of the currency. In May 2008, the Bank of Russia proposed a scheme to increase the foreign exchange reserves to equilibrate the demand-supply mismatch in the foreign exchange market. After the global financial crisis in 2008, the sharp fall in oil prices led to deterioration in the current account balance leading to massive capital outflow and depreciation of Ruble. To counter the situation, the central bank raised interest rates and intervened in the foreign exchange market to prevent the large currency depreciation.

In January 2009, the Ruble value of the dual currency basket was allowed to fluctuate in a more widened fixed band. Simultaneously, a floating operational band was introduced to enable the market participants to eventually adopt a fully floating exchange rate system. During 2009–12, the Bank of Russia followed a policy of increasing the flexibility of the exchange rate by lowering the extent of intervention in the foreign exchange market and in the process adding up to the importance of focusing on the interest rate policy. Nevertheless, the Bank of Russia continued with its policy of increasing the flexibility of the exchange rate with an aim to make the exchange rate regime fully floating by 2015. The monetary authority, however, has reserved the right to intervene in the currency market to manage large changes in the exchange value.

Exchange rate policy of Reserve Bank of India

The exchange rate system underwent changes towards a unified exchange rate system through merging of a dual exchange rate system and finally towards current account convertibility in the early 1990s. In March 1992, with the introduction of The Liberalized Exchange Rate Management System, a dual exchange rate system was established, which was designed to liberalize trade by subsidizing imports and initiate a move towards partial convertibility of Indian Rupee. In March 1993, as per the recommendations of the Rangarajan Committee, the dual exchange rate system was replaced by unified exchange rate system, which along with removal of exchange restriction on imports through the abolition of foreign exchange budgeting are the initial steps towards current account convertibility. The final step towards current account convertibility was taken in August 1994 by further liberalization of invisible transactions and exchange control regulations up to a specified limit.

Since 1996, wide-ranging reforms were introduced in the Indian foreign exchange market. There was a gradual opening of capital account and greater integration of the Indian financial markets with the global network since 2003-04. Nonetheless the Reserve Bank, when needed, acts in the exchange market using direct and indirect monetary and regulatory measures to restore equilibrium in the foreign exchange market. With intermittent volatility in the nominal exchange rate, the Reserve Bank intervenes in the foreign exchange market by selling and purchasing of foreign currencies.

Exchange rate policy of People's Bank of China

Since late 1970s, the Chinese exchange rate regime has changed from a fixed one through a dual regime[26] between 1986 and 1993 to a unified managed float in 1994. In 1995, the Renminbi (RMB), also known as Yuan, was de facto fixed to the US dollar following a short period of appreciation of nominal exchange rate. During the Asian financial crisis in 1997-98, the RMB was fixed at 8.3 Yuan per US dollar inspite of a number of adverse factors prevailing in the economy. The People's Bank of China (PBC), at times, conducted large interventions to keep the exchange rate stable which resulted in increase in reserves of more than 30% of GDP by 2004. After widespread reforms in financial institutions, the central bank announced its policy of adopting a managed float but with reference to an undisclosed basket of currencies. Nonetheless, the exchange rate regime remained closely associated with US dollars with a prevailing daily rate, called the central parity rate, announced at the start of each trading day which was allowed to fluctuate within a specified band. Besides, the PBC also revaluated the RMB exchange rate against the dollar in July 2005 by 2.1 percent to 8.11 Yuan per dollar[27], thereby allowing the currency to fluctuate within the band of ± 0.3 percent. This band was increased to ± 0.5 percent in May 2007 and further widened to ± 1 percent in April 2012 and ± 2 percent in March 2014. The PBC practiced this management of semi-fixed exchange rate by imposing widespread capital controls and prohibitive measures.

Since the global financial crisis in 2008, with fall in export demand of Chinese products globally, the monetary authorities temporarily suspended the appreciation of the RMB till June 2010. However, the PBC again allowed the currency to find its equilibrium

[26] The official rate with sporadic adjustments coexisted with the market-determined rate, but the latter was set at a relatively depreciated level as compared to the official rate.
[27] The RMB further appreciated by 18.7 percent to 6.83 Yuan per dollar during the period upto July 2008.

level, the currency appreciated by 10.7 percent to 6.17 Yuan per dollar in July 2013. With growing foreign exchange reserves from US$ 733 billion in July 2005 to US$ 3.99 trillion in June 2014, the currency appreciated by 26 percent between July 2005 to July 2015.[28] In August 2015, the PBC announced further flexibility of RMB exchange rate which triggered a depreciation of the currency of about 8.8 percent during the period till December 2016. This was also followed by huge capital outflows, acquisition of foreign assets by domestic residents and capital flights. In response, the PBC intervened to counter the depreciation at the cost of large depletion the foreign exchange reserves.[29] Nonetheless, the depreciation pressure on RMB eased off steadily followed by appreciation of about 4.6 percent during January to December 2017.

Despite fluctuations, the PBC again initiated steps towards a more floating exchange rate system in first half of 2018. Despite short run management of the exchange rate, adjustments are allowed to arrive at a long run equilibrium. As per the IMF's 2018 External Sector Report, the RMB exchange rate, in 2017, was considerably in line with the fundamentals. Furthermore, China has been pitching for internationalisation of the RMB with opening up of an offshore RMB markets in several countries including in Hong Kong SAR in 2010. In addition, the RMB was also included in the Special Drawing Rights basket of the IMF in 2015.

Exchange rate policy of South African Reserve Bank

The exchange rate regime in South Africa started changing since the mid-1980s with the introduction of a dual currency system with both the commercial Rand and

[28] The appreciation of NEER and REER was 44 and 58 per cent respectively.
[29] The foreign exchange reserves decreased by US$ 321 billion in the second half of 2015 to offset the depreciation pressure of the RMB.

financial Rand being allowed to float freely.[30] The currency fluctuated during 1986-88, which continued in early 1990s. In 1992, South African central bank liberalised the norms for overseas investment by the residents and increased the supply of Rand to approve these investments which led to Rand depreciation. However the policy of not allowing South African companies to access the financial rand market, if the investments are not beneficial to the country in short run, led to the appreciation of the Rand. Finally, following the democratic elections in 1994, the Rand appreciated. Later on, in March 1995, the dual exchange rate was again changed to a unified exchange rate.

The South African Reserve Bank (SARB) intervenes at regular intervals to mitigate any kind of depreciating effect on the Rand. The intervention by SARB in the foreign exchange market comprises of a combination of both spot and forward transactions. This type of intervention by the central bank was used widely through 1996-98. In response to a large depreciation in 1996, SARB intervened in the foreign exchange market by increasing the forward book to US$ 22 billion and subsequently the net open foreign exchange position (NOFP)[31] was reduced to US$ 10 billion in 1997. The crisis in 1998, however, resulted in an increase of the NOFP. However, the central bank was successful in reducing the NOFP to US$ 9.5 billion by end 2000, but at the same time, the Rand depreciated on trade-weighted basis by 12.4 percent. By end 2001, the Rand almost depreciated by 40 percent reaching to R13.84 per USD, but SARB maintained its stand of not intervening in the market and allowing the exchange rate to be market

[30] The commercial rate is set in accordance with the current account transactions whereas the financial rate is set in accordance with capital account transactions. The financial Rand system was a type of exchange control introduced by the Central Bank, where investments made by non-residents can only be sold with financial Rand under strict conditions of convertibility into foreign currency.

[31] Net open foreign currency position (NOFP) is defined as the net outstanding balance of all assets, liabilities and off balance sheet items in terms of a particular foreign currency.

determined. After the abolishment of NOFP, the SARB was successful in increasing its reserves since 2003. The official foreign exchange reserves elevated from a negative NOFP of US$ 1.4 billion to an international liquidity position of US$ 47.9 billion by December 2012. The Rand also fluctuated during 2013-17 on account domestic events like the announcement of the removal of the finance minister, winning of a no confidence motion by the president by small margin, the stepping down of the budget chief, or international events including the economic slowdown of China or the Brexit. Although SARB is committed to take steps to offset any unruly condition in foreign exchange market, it is more inclined in building up of the official reserves and managing domestic liquidity. On the whole, the central bank in South Africa does not set a target level for the exchange rate of Rand, rather allows the market forces to determine the exchange rate.

The above discussion establishes that Brazilian Real and South African Rand have evolved into a more flexible exchange rate regimes as compared to the currencies in China, India and Russia. The latter economies are found to follow a regime of managed float. The BCB and SARB allow high capital account convertibility whereas the central banks of Russia, India and China undertake partial current account convertibility. Even though the BCB and SARB intervene in the foreign exchange to contain any kind of excess volatility in currency, they are more committed to allow the exchange rate to be market determined. In contrast, the People's Bank of China has conducted widespread intervention in the foreign exchange market to maintain the exchange rate at a level which is conducive to their economic conditions. The Chinese monetary authorities gradually reformed the RMB exchange rate to match with the Chinese economic and financial systems. The RMB is more flexible with respect to US dollar thereafter.

On a whole, these brief discussions have shed light on the changing phases in exchange rate policies in the BRICS economies and the commitment of the respective central banks to gradually move to a more floating regime, wherein market forces play a major role in exchange rate determination. It is probably because of lesser intervention that the Brazilian Real and South African Rand are more volatile among BRICS currencies. In this context of changing exchange rate policies, it is important to understand the currency markets movements in individual BRICS countries.

1.4 BRICS CURRENCY MOVEMENTS: SOME STYLISED FACTS

In an earlier section, it is observed that BRICS currencies show intermittent volatility during 2006-2018. With a view to understanding the BRICS currency movements, the descriptive statistics of the returns series[32] of Brazilian Real, Russian Ruble, Indian Rupee, Chinese Yuan and South African Rand for the period 2006-2018 are presented in Table 1.2. It is evident from the table that the mean return is negative for Chinese Yuan, while it is positive for Indian Rupee, Brazilian Real, South African Rand and Russian Ruble. In case of foreign exchange markets, a negative return generally implies an appreciation of the currency and vice versa. Accordingly, a negative mean return for Chinese Yuan as against positive returns for other currencies would imply higher return for the Chinese currency as compared to other BRICS currencies. Moreover, the variation in currency returns measured by standard deviation is the highest for South African Rand followed by Brazilian Real, and Russian Ruble. It is interesting to note that the variations in returns for the Indian and Chinese currencies are lower than

[32] The return on each foreign exchange is calculated by taking the first logarithmic differences in exchange rate denoted as: $\Delta \ln S_t = \ln S_t - \ln S_{t-1}$, where S_t is home-to-foreign exchange rate.

that for other BRICS currencies. This is possibly an indication of significant interventions by the respective central banks in these two countries.

Table 1.2: Descriptive Statistics of BRICS Currency Returns (with respect to US $)

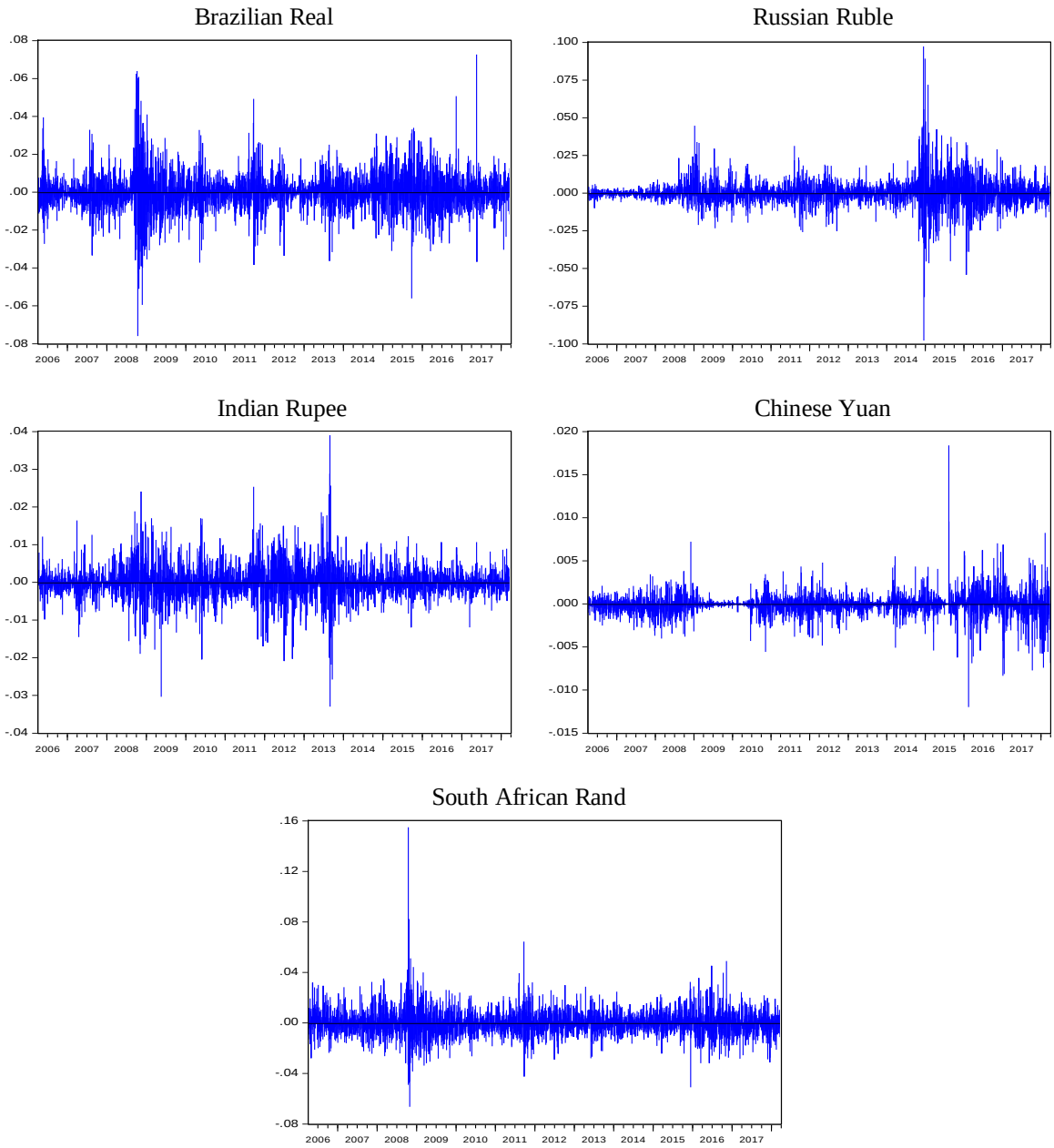
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
Mean	0.00014	0.00023	0.00012	-0.00008	0.00021
Std. Dev.	0.01051	0.00912	0.00461	0.00137	0.01112
Variance	0.000110	0.000083	0.000021	0.000002	0.000124
Skewness	0.32011	0.53920	0.22310	0.47580	1.11093
Kurtosis	8.74233	20.07363	9.62944	20.99448	17.48595
ADF Test	-59.62022 (0.000)***	-53.15491 (0.000)***	-41.05777 (0.000)***	-22.40415 (0.000)***	-41.97764 (0.000)***
JarqueBera	4353.86 (0.000)***	38169.28 (0.000)***	5757.71 (0.000)***	42347.21 (0.000)***	28010.83 (0.000)***
Q(30)	65.846 (0.000)***	132.32 (0.000)***	73.935 (0.000)***	114.05 (0.000)***	53.347 (0.005)***
$Q^2(30)$	4372.8 (0.000)***	4175.4 (0.000)***	1879.4 (0.000)***	270.07 (0.000)***	780.81 (0.000)***
Obs.	3130	3130	3130	3130	3130

*Notes: ***, ** indicates significance at 1 percent and 5 percent level; p-values are in the parentheses.*
Q(1) and $Q^2(1)$ is the Ljung-Box statistic for serial correlation in return series and squared series respectively.

The kurtosis coefficients being greater than 3, indicate that the BRICS currency returns series are leptokurtic, implying that currency returns follow a non-normal distribution. Further, the significance of Jarque-Bera statistics also confirms non-normality of currency returns series. The table also reports the Ljung-Box Q and the Q^2 statistics for all return series and the squared return series. The Q statistic results point to the fact that the currency returns series cannot be characterized to follow a random walk process, the Augmented Dickey-Fuller test shows that all the return series are I(0). The Q^2 statistic, on the other hand, is significant for each return series showing the presence of higher order serial correlation and non-linearity among the variables. The significance of Q and Q^2 statistic alternatively suggest the presence of ARCH effect in the residuals.

Some more evidence on the time pattern of volatility for BRICS currency returns are shown in Figure 1.2. The amplitude of fluctuations in the return series appears to be larger for most BRICS countries than for China, thus confirming the findings in Table 1.2. Volatility also seems to have clustered during 2008, 2009, 2011, 2015 and 2016 for

Figure 1.2: Time Pattern of BRICS exchange rate return



Brazilian Real, Russian Ruble, Chinese Yuan and South African Rand, whereas in case of Indian Rupee, volatility clustering occurs during 2008, 2009 and 2011-2013. These series thus exhibit non-randomness, volatility clustering and ARCH effect.

On the whole, the stylized facts of all the return series exhibit volatility and volatility clustering during the entire sample period. This finding is possibly suggests that the observed volatility pattern across BRICS currencies for a large part of the sample period can be either on account of some domestic or external shocks arising out of the changes in exchange rate policy regimes, uncertainties arising out of other policy changes or the spillover effect of some crises that originated elsewhere in the global economy. The analyses that follow attempt to bring out the various facets of BRICS foreign exchange markets by identifying the phases of such volatility, the extent of volatility spillover from various developed country currencies and the impact of EPU indexes on the BRICS foreign exchange markets.

1.5 OBJECTIVES OF THE STUDY AND SUMMARY OF FINDINGS

The research objectives of the thesis are:

- Examining the pattern of regime switching behaviour and volatility in the BRICS foreign exchange markets. Here, using a Markov switching autoregressive framework, the behaviour of the BRICS foreign exchange returns is explored in a two-state Markov regime i.e. the bullish and the bearish regimes. The shifts between the two regimes are identified along with persistence of each regime. In addition, exchange market pressure and the intervention index are estimated to analyse the pressure on individual BRICS

currency to appreciate or depreciate and interventions by the respective central banks to contain such market pressure.

- Investigating into the extent of connectedness in foreign exchange markets of BRICS countries with various other countries. In specific, the thesis explores into of return co-movement and volatility spillover between BRICS currency markets and some developed country currencies whose turnover of all transactions are high.
- Exploring whether economic policy uncertainty impacts on the volatility of BRICS currencies.

As empirical strategy, the essays use time series analysis on BRICS exchange rate data. While a brief discussion on the database is given Appendix 1.I, the methods are detailed in individual essays. The econometric analysis identified Chinese Yuan to have lower volatility in both bear and bull regimes. On the other hand, South African Rand has high variance in both the regimes. Further, the market synchronization analysis shows synchronous movements in currency returns, thereby indicative of less opportunity for portfolio diversification. The empirical analyses further shows significant return co-movement among the foreign exchange markets with BRICS foreign exchange markets, except Brazil and Russia, as net receivers of volatility and developed markets are net transmitter of volatility. The investigation further reveals that South African Rand is the highest receiver of volatility among other BRICS foreign exchange markets. The empirical results also show that the exchange rate volatility of the BRICS countries are primarily dependent on recent past volatility and are mostly affected by own country economic policy uncertainty (EPU) index and US EPU. However, the effects of local EPU and the US uncertainties are found to be low in case of Chinese Yuan.

1.6 CHAPTER SCHEME

The thesis comprises of three core essays[33] dealing with the three objectives mentioned above. The structure of the thesis is as follows: Chapter 2, the first essay, deals with predicting regime switching in BRICS currency volatility in a Markov switching autoregressive framework. Chapter 3, the second essay, investigates into return co-movements and volatility spillover in BRICS currency markets. Chapter 4, the last essay, explores the effect of economic policy uncertainty on BRICS currency volatility. Finally, Chapter 5 concludes with summary of major findings and policy implications for policy.

[33] In this thesis, each essay on exchange rate volatility deals with an objective, which is carried out in a chapter. As a result, 'essay' and 'chapter' are used interchangeably in the study.

APPENDIX 1.I

DATA APPENDIX

Data on daily nominal spot exchange rate are used in this dissertation to analyse the three important aspects of foreign exchange markets. The use of spot exchange rate instead of forward exchange rate in the study can be rationalised in terms of the covered interest rate parity condition. The covered interest rate parity is a no-arbitrage condition where the investors are indifferent between interest bearing bank deposits in two currencies as the exchange risk is covered using a forward contract. In general, investors decide on the forward rate by taking into account the spot rate and the interest rates on bank deposits designated in currencies of their choice. So any change in the spot rate and interest rates will change the forward rate. Given this condition, the using of forward rate may lead to a misperception as it would be difficult to understand the changes in forward rate as forward rate may change following a change in either spot rate or interest rates or both. More specifically, the change in forward rate may not reflect the true picture prevailing in the foreign exchange market and may lead to misleading conclusions. To avoid this situation, spot exchange rate is used in the study.

The database covers the daily exchange rate returns of BRICS currencies vis-à-vis Brazilian Real, Russian Ruble, Indian Rupee, Chinese Yuan and South African Rand. The study is carried out for the period April 2006 to March 2018. Te data are obtained from Bloomberg data base (https://www.bloomberg.com). Bloomberg is a widely recognized and reliable data platform which provides financial software tools and enterprise applications such as analytics and equity trading platform, data services and

news to financial companies and organsations. Research and market analysis are carried out using real time financial market data taken from the database.

For analyzing the Markov regime switching model, daily exchange rate returns of individual BRICS currencies are used. For estimating the Exchange Market Pressure (EMP), the monthly data on money supply, index of industrial production, consumer price index and interest rate, are availed from OECD database (http://data.oecd.org). In this regard, the data on daily exchange rate are converted to monthly rate using simple averages. For this purpose, the monthly data on foreign exchange reserves for BRICS countries are availed from the database of Federal Reserve Bank of St. Louis (https://fred.stlouisfed.org).

In order to analyse the return co-movements and volatility spillover, the daily exchange rate series of developed countries including Euro, Japanese Yen, British Pound, Australian Dollar vis-à-vis US Dollars along with that of Brazilian Real, Russian Ruble, Indian Rupee, Chinese Yuan and South African Rand are used. The choice of developed country currency like Euro, Japanese Yen, British Pound and Australian Dollar is based on the Bank for International Settlements (BIS) Triennial Central Bank Survey (2016), where these currencies are found to be among the world's top five most traded currency. The BIS Triennial Central Bank Survey shows that the turnover of all transactions of these currencies, including the spot transactions, outright forwards, foreign exchange swaps, currency swaps and foreign exchange options, are US$ 1,591 billion, US$ 1,096 billion, US$ 649 billion and US$ 348 billion respectively in 2016.

Finally, to investigate the effect of Economic Policy Uncertainty (EPU) on the volatility of BRICS exchange rate, data on monthly exchange rate series of Brazilian

Real, Russian Ruble, Indian Rupee, Chinese Yuan and South African Rand (BRICS) are used. In addition, the own country economic policy uncertainty (EPU) index of Brazil, Russia, India and China are used to assess its impact on the exchange rate volatility of BRIC[34] countries. Moreover, since the exchange rates of the BRICS countries are with respect to US Dollars, it is imperative to take into the account the effect of US EPU, if any, on the BRICS foreign exchange rate volatility. These indexes, provided by Baker et al. (2016), are news based policy uncertainty index obtained by counting the number of news articles containing a variety of country-wise uncertainty terms published therein.

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[34] It is important to note here that the EPU Index of South Africa is not available. So its impact on the volatility of the South African Rand could not be analysed.

CHAPTER 2

Regime Switching in BRICS Currency Volatility[1]

2.1 INTRODUCTION

In this essay, an attempt is made to understand the changing behaviour of BRICS currency volatility. BRICS exchange rates, as observed in Chapter 1, are found to fluctuate switching from low to high and vice versa, thereby leading to regime[2] shifts. As evident from Chapter 1, the time path of BRICS currency returns show high volatility and volatility clustering during 2006-2018. The standard deviation statistic reveals that South African Rand fluctuates more widely than other BRICS currencies, while the dispersion is less in cases of Chinese Yuan and Indian Rupee. Individual currency markets are found to be turbulent for a large part of the sample period.

The literature reviewed as well as the stylized facts presented in the earlier chapter shows that increasing flexibility in BRICS currency markets could have led to such widely varying exchange rates in these economies. The trigger for such wide variations in currency values, and hence returns, can also be on account of either external or domestic shocks. In response to such variations arising out of exchange market pressure, the respective central bank of these emerging market economies, like any others, formulate exchange rate policies and intervene intermittently in the foreign exchange market to maintain the exchange value of the domestic currency. Post global

[1] A version of this chapter is published in a paper titled "Predicting Regime Switching in BRICS Currency Volatility: a Markov switching autoregressive approach", *Decision – Official Journal of the Indian Institute of Management Calcutta*, 48 (2):165-18, 2021. [Springer**:** https://doi.org/10.1007/s40622-021-00275-9]

[2] As mentioned in Chapter 1, as is dealt with here in this essay, the concept of 'regime' shifts refers to changes from bear to bull regime or vice-versa. The regime switching analysis is carried out using a Markov Switching Model. Such regimes, however, do not necessarily imply exchange rate regimes.

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financial crisis of 2008, the Basel III norms introduced enhanced risk management mechanism in the banking system to counter persistent exchange rate volatility.

In particular, this chapter investigates into the pattern of regime switching behaviour of volatility of BRICS currencies using a Markov switching autoregressive model. In addition, it examines Exchange Market Pressure (EMP) to understand the pressure on each currency to appreciate or depreciate. According to Weymark (1995), Exchange Market Pressure measures the total excess demand for a currency in international markets, where changes in exchange value are required to balance situations of excess demand in the absence of exchange market intervention. Estimation of intervention index in this context would show the extent to which respective central banks intervene to contain such exchange market pressure.

Predicting the behaviour of exchange rates and modelling it is a challenge for the economists, with Meese & Rogoff (1983 a, b) opining that fundamentals-based exchange rate models are inappropriate to forecast exchange rate changes for less than a year. The Markov Switching Model (MSM) by Engel & Hamilton (1990) has become important in this regard with several studies failing to invalidate the Meese & Rogoff findings.[3] Engel & Hamilton (1990) suggest that the MSM provides a framework in which regimes are characterized by a combination of low and high mean exchange rate and volatility, and develop a new statistical model of exchange rate dynamics, which when employed shows long-swing in Dollar and outperforms the random walk model. The use of Markov switching model merges two different strands of literature: the first strand uses ARIMA models to forecast out of sample exchange rates (Neely et al. 1997); the other strand

[3] Meese & Rose (1991), Neely & Sarno (2002), and Killian & Taylor (2003) provide supportive evidence to Meese & Rogoff (1983 a, b).

forecasts exchange rates using Markov switching models of lower frequency (Engel & Hamilton, 1990; Engel, 1994). The main purpose of this genre of regime switching stochastic models is to take into account important aspects of the data including mean trend gap that can be observed at different points of time.

The structure of the chapter is as follows: Section 2.2 provides with a review of the existing literature on the subject and section 2.3 delineates the econometric methodology and the data used in the study. Section 2.4 presents the empirical results. Section 2.5 summarises the major findings of the empirical analysis in this chapter.

2.2 REVIEW OF LITERATURE

Regime shifts are usually captured in the literature taking recourse to regime switching models. Markov switching model is one such model. The Markov switching model, introduced by Goldfeld & Quandt (1973), captures discrete shift in the data generating process in a time series (Hamilton 1988, 1989). Engle & Hamilton (1990) view that MSM to be a good approximation to the underlying processes with good predictive power of non-linear time series (Hamilton, 1994). Since then, a large literature on regime-switching models has emerged covering theoretical extensions as well as empirical applications to economic and financial variables.[4]

Regime-switching in exchange rate, both nominal and real, has been documented by Bekaert & Hodrick (1993), Engel & Hakkio (1996), and more recently, Bergman & Hansson (2005) and Lee & Chen (2006). These papers provide empirical evidence that

[4] For instance, some papers dealing with stock markets dynamics, other financial markets and oil markets in MSM framework are Guidolin &Timmermann (2006), Chesnay & Jondeau (2001), Tillmann (2004), Qiao et al. (2011), Chkili et al. (2011), Thomadakis (2012), Chan et al. (2011) and Dua & Tuteja (2016). Das & Sinha Roy (2020) provide a detailed review of this set of studies.

regime-switching models typically outperform single regime exchange rate models. Further, many studies advocate that these models fit exchange rate data well and generate better forecasts as compared to any random walk or other models (Nikolsko-Rzhevskyy & Prodan, 2012). Some authors also show the use of regime-switching models for financial sector variables including the valuation of currency options (Bollen et al. 2000).[5] Kumah (2011) confirms the statistical superiority of the nonlinear regime-switching model over a linear VAR in understanding EMP.

However, Engel (1994), for 7 USD and 11 non-USD exchange rate series, finds that the Markov switching model fits well in-sample for many exchange rates, but is not able to generate forecasts which are superior to the random walk according to either the Mean Square Prediction Error (MSPE) or mean absolute error (MAE) criteria. Klaassen (2005) extends Engel's model with a GARCH error structure, but fails to find any nominal exchange rate predictability using the MSPE criterion. Goutte & Zou (2013) compare the results on goodness of fit of different regime-switching models against non-regime switching ones on foreign exchange rate data and show that regime-switching models with both mean reverting and local volatility structures fit the data well. Moreover, such modelling captures crises or changes in the dynamic level of variance. Dewachter (2001) extends the MSM by introducing separate and independent latent variables for the dynamics in mean and variance. With regards to currencies, such as German Mark, Euro, Yen, British Pound and Swiss Franc, Dueker & Neely (2007) find that Markov model generates significant and more stable out of sample excess returns.

[5] In recent years, a large number of studies have used MSM to predict future price movements and to capture volatility dynamics of stock markets (see Balcilar et al. 2015)

Shen & Chen (2004) show that developed countries experience symmetric swings in exchange rates, while adjustment speeds may be asymmetric in developing countries.

Marsh (2000) adds the fundamental factor to the model, uses interest rates to investigate the daily variations in exchange rates. Caporale & Spagnolo (2004) show that exchange rate behaviour in East Asian countries is non-linear. Frommel, MacDonald & Menkhoff (2005 a, b) find that the factors that were closely related to regime switches were short-term interest rates, inflation differentials and differences in economic growth. The applications of the MSM thus capture some major dynamics that characterize exchange rate behaviour, although the structure may vary over time.

This regime switching in the foreign exchange markets, often referred to as Exchange Market Pressure (EMP), occurs on account of shocks originating during crisis periods or because of speculative or trading activity by the policy authorities or investors, among other factors. The exercise on exchange market pressure provides with an important understanding of exchange rate management in terms of the volume of intervention necessary to achieve any target exchange rate. For instance, Girton & Roper (1977) show that exchange market pressure provide a measure of the volume of intervention necessary to achieve any desired exchange rate target in post-war Canadian economy. Weymark (1995), using quarterly bilateral and multilateral estimates of EMP and the degree of exchange market intervention for Canada, shows that the prime target of intervention by Bank of Canada was the bilateral Canadian Dollar-U.S. Dollar exchange rate.

Aizenman & Hutchison (2012) show that emerging markets having high foreign liabilities are more exposed to financial crisis whereas countries with large balance sheet

exposure absorb the global shock by depreciating the exchange rate rather than losing reserves. Kumah (2011) identifies episodes of EMP in the Kyrgyz Republic in a three regime MSM. Feldkircher et al. (2014) explain that EMP is determined by price stability and that international reserve reduces the volatility of EMP. Aizenman & Binici (2016), show in addition, that external factors and short-term gross portfolio inflows and outflows drive EMP for OECD and emerging market economies. Moreover capital controls reduce the EMP depending on institutional quality. Baig et al. (2003) show that the RBI often prevents the appreciation of Indian Rupee while preferring some degree of depreciation of the currency. The study also suggests that the RBI resort to sale of foreign currency during the crisis period and opts for sterilised intervention. Patnaik et al. (2017) develop an estimate of EMP, to measure the changes in exchange rate associated with currency intervention worth US$1 billion, by assuming similar macroeconomic shocks before and after the change in the exchange rate regime. This model compares well across countries and time.

The above-mentioned papers provide an insight into the exchange rate movements modelled in a Markov switching framework, followed by an analysis of the degree of intervention, primarily in terms of intervention index, being conducted by the respective central banks to stabilize the currency. It is important to mention here that there are few studies which have looked into the aspect of Exchange Market Pressure and there are even fewer studies which have dealt with both Markov Switching Model and Exchange Market Pressure simultaneously. One such paper, by Fiess & Shankar (2009), finds that the exchange rate policy of the central banks primarily depends on the financial and economic fundamentals. Using a monetary model, the paper derives a policy reaction

function for the central bank where the money market disequilibrium causes exchange market pressure, which is neutralized by intervention, directly or indirectly, in the foreign exchange market. Moreover, to identify the shifts in the exchange market intervention, the study estimates a two-state Markov switching autoregressive model with regime shifts in the mean of policy response indices and shows that policy regimes are mainly driven by country-specific constraints.

The entire range of literature reviewed above gives an idea about the changes in the foreign exchange market behaviour from depreciation to appreciation and vice versa.. This section not only provides an overview of regime switching models used in identifying regime shifts with regard to volatility in foreign currency market but also modelling exchange market pressure and measuring the extent of intervention in foreign currency markets. However, the literature on regime switching – from bear to bull and vice versa – in foreign currency markets is less relative to that on other asset markets and that too in BRICS countries. This chapter attempts to classify the mean return and volatility in BRICS currencies by modelling a two-state Markov switching process. The chapter also analyses exchange market pressure and constructs an intervention index to understand the level of intervention that is carried out by respective central banks in case of any situation of excess demand in the foreign exchange market.

2.3 THE METHODOLOGY

In this sub-section the Markov Switching-Autoregressive model is discussed. Quandt (1972) constructs a switching model where the state variable is an *iid* random sequence. In another paper, Goldfeld & Quandt (1973) propose a switching regression model with state variable as a two-state hidden Markov chain process. Hamilton (1989,

1990) extends the Goldfeld & Quandt (1973) model by allowing for regime shifts. The estimation model used here, based on Hamilton (1989), proposes a time-series variable y_t by a Markov switching autoregressive of order k with regime switching-in mean and variance. The proposed model is as follows,

$$y_t = \mu(S_t) + \sum_{i=1}^{k} \varphi_i \left(y_{t-i} - \pi(S_{t-i})\right) + \sigma^2(S_t)\varepsilon_t \quad \ldots\ldots(2.1)$$

where y_t is the BRICS foreign exchange market return, μ is the mean and σ^2 is the variance depending on the regime S_t at time t, φ_i is the autoregressive coefficient, S_t and S_{t-i} are the unobserved states which takes the value 1 or 2 and the transition probabilities p_{ij} between the states are as follows:

$$p_{ij} = \Pr(S_t = j | S_{t-1} = i) \text{ with } \sum_{j=1}^{2} p_{ij} = 1 \text{ for all } i, j \in [1,2] \quad \ldots\ldots(2.2)$$

where,

$$\left.\begin{array}{l} Prob\,(S_t = 1|S_{t-1} = 1) = P_{11} \\ Prob\,(S_t = 1|S_{t-1} = 2) = 1 - P_{11} \\ Prob\,(S_t = 2|S_{t-1} = 2) = P_{22} \\ Prob\,(S_t = 2|S_{t-1} = 1) = 1 - P_{22} \end{array}\right\} \quad \ldots\ldots..(2.3)$$

where P_{11} is the probability of being in regime 1 given the system was in regime 1 in the previous period, P_{22} is the probability of being in regime 2 given that the system was in regime 2 in the previous period. The transition regime, $1 - P_{11}$ is the probability that S_t will shift to state 1 in period t from state 2 in period $t-1$ and $1 - P_{22}$ is the probability that S_t will shift to state 2 in period t from state 1 in period $t-1$. Nonetheless, the state dependent mean and variances, following Wang & Theobald (2008), are described as:

$$\mu_{(S_t)} = \mu_t S_{1t} + \ldots. + \mu_{m1} S_{mt} \quad \ldots..(2.4)$$

$$\sigma^2{}_{(S_t)} = \sigma_1^2 S_{1t} + \ldots. + \sigma_{m1}^2 S_{mt} \quad \ldots\ldots(2.5)$$

where S_{mt} takes the value 1 when S_t is equal to m and 2 otherwise (Kim & Nelson, 1999). The MSM assumes that ε_t and S_t are independent, as shown in equations 2.1, 2.4 and 2.5, implying that the change in regime does not depend on past history. The parameters of Markov switching model is estimated by maximum likelihood method, which is performed using the EM algorithm, as described in Hamilton (1989, 1990).[6]

In order to estimate Exchange Market Pressure (EMP) and the Intervention Index, a small open economy model specification is used[7] where purchasing power parity does not hold and foreign prices and the exchange rate are assumed to influence domestic prices. Following Fiess & Shankar (2009), EMP can be dealt in three possible manners by: i) adjusting the exchange rate; ii) adjusting the interest rate; and iii) direct or indirect intervention in the foreign exchange market. For instance, if the central bank is involved in unsterilized intervention, then EMP is defined as[8]

$$EMP_t = \Delta e_t + \eta \Delta r_t \qquad \text{.....(2.6)}$$

where Δe_t is the change in exchange rate, Δr_t is the change in foreign exchange reserves and η = - $\partial \Delta e_t / \partial \Delta r_t$ is the elasticity which converts changes in reserves into equivalent units of exchange rate changes. To measure the degree of intervention in case of any EMP, the following intervention index, as defined by Weymark (1995), is used

$$\omega_t = \frac{\eta \Delta r_t}{EMP} \qquad \text{.....(2.7)}$$

---

[6] For details, see Hamilton (1989, 1994) and Krolzig (1997, 2001).

[7] The detailed description of the small open economy monetary model used to estimate Exchange Market Pressure (EMP) is illustrated in Girton & Roper (1977) and Weymark (1995).

[8] In a recent study, Patnaik et al. (2017) describe EMP by assuming that a country was exposed to both fixed and floating exchange rate regime and it intervenes only during fixed regime, and not during floating regime, to influence the exchange rate. Therefore, $EMP_t = \Delta e_t + \rho_t I_t$ and $EMP_{float} = \Delta e_t$; $EMP_t = \rho_t I_t$, where $\rho_t = \left(\frac{Var\,(\Delta e_{float})}{Var\,(I_{fixed})}\right)^{\frac{1}{2}}$. In order to estimate ρ_t, countries which have experienced both the exchange rate regimes are required to be chosen.

However, equation (2.7) is modified following Kaminsky and Reinhart (1999) by setting η equal to the ratio of the standard deviation of the rate of change of exchange rate and standard deviation of the rate of change of foreign exchange reserves, i.e. $\eta = \sigma_{\Delta e_t}/\sigma_{\Delta r_t}$. Thus, equation (2.7) can be written as,

$$\omega_t = \frac{(\sigma_{\Delta e_t}/\sigma_{\Delta r_t})(\Delta r_t)}{(\sigma_{\Delta e_t}/\sigma_{\Delta r_t})(\Delta r_t) + \Delta e_t} \quad \text{.....(2.8)}$$

Further, the market synchronization analysis explores the association among the currency markets by measuring the unconditional correlation between the logits of the smoothed probabilities of the bull and bear regimes of the respective BRICS currencies. The analyses that follow are based on the econometric estimation results arrived at using the methods delineated above and the database described in Appendix 1.I in Chapter 1.

2.4 THE EMPIRICAL RESULTS

The estimation results of two-state Markov switching model to identify regime specific mean and volatility of the BRICS foreign exchange markets are detailed out in this section. This is followed by the analysis of Exchange Market Pressure to bring out the various phases of large appreciation or depreciation in the BRICS currencies and the intervention undertaken by the respective central banks to contain in such large changes in the respective currency value. The econometric estimation results that follow identify the phases of such large appreciation or depreciation and the extent of intervention by respective central banks to contain in such wide variations.

2.4.1 Markov Switching Analysis

The univariate Markov switching analysis of the BRICS currencies is looked into using the two-state regime switching behaviour of each currency, the two-states being

bullish and bearish. The estimation is carried out using Equation 2.1. From Table 2.1, it can be noted that the BRICS currency returns are negative in regime 1 and positive in regime 2, except for Chinese Yuan. Regime 1 can thus be characterized as bearish and regime 2 as bullish, which is in conformity with the literature on Markov switching analysis.[9] The transition regimes from regime 1 to 2 and vice-versa is arrived at by using Equation 2.3. Among the BRICS currencies, the highest return during the bearish regime (μ_1) is observed for Brazilian Real followed by Russian Ruble, Indian Rupee, South African Rand and Chinese Yuan and whereas the highest return during the bullish regime (μ_2) is found in case of Chinese Yuan followed by Indian Rupee, Russian Ruble, Brazilian Real and South African Rand. Further, the highest volatility in both regime 1 (σ_1) and regime 2 (σ_2) is observed for South African Rand followed by Brazilian Real, Russian Ruble, Indian Rupee and Chinese Yuan. It is important to note, in most BRICS currency markets, the bearish regime represents appreciation with low volatility as compared to that in a bullish regime. It is also evident from the table that Chinese Yuan, among others, has the lowest return and low volatility during the bearish regime. On the other hand, during the bullish regime, South African Rand has the lowest return with highest volatility while Chinese Yuan has the highest return with lowest volatility.

With regards to the duration of stay (in days) of the foreign exchange markets in each regimes, it further can be observed from Table 2.1 that South African Rand has the highest persistence during the bearish regime followed by Brazilian Real, Russian Ruble, Indian Rupee and Chinese Yuan. During the bullish regime, persistence is higher for

[9] It is important to mention here that, in foreign exchange markets, a bearish regime is the regime of appreciation of the currency as the returns are negative whereas the bullish regime is indicative of currency depreciation with positive returns.

Brazilian Real than other BRICS currencies. The duration of stay, considering both the regimes, is the longest for South African Rand, while it is the shortest for Chinese Yuan.

Table 2.1: Estimates of univariate Markov switching model of BRICS currency markets

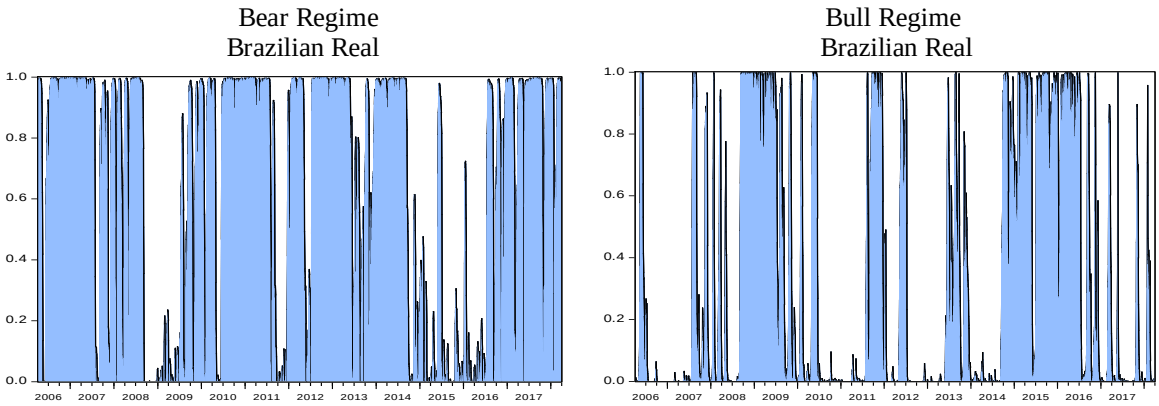
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
μ_1	-0.000343*** (0.000131)	-0.000150** (0.000094)	-0.000109 (0.000088)	-0.000055*** (0.000015)	-0.000062 (0.000128)
μ_2	0.001075** (0.000440)	0.000993** (0.000469)	0.000531*** (0.000203)	-0.000115** (0.000054)	0.001473 (0.000963)
σ_1	0.006281*** (0.025110)	0.004252*** (0.024093)	0.002493*** (0.056887)	0.000537*** (0.034247)	0.00855*** (0.024291)
σ_2	0.015689*** (0.030975)	0.014504*** (0.027161)	0.006921*** (0.033431)	0.002085*** (0.026249)	0.018805*** (0.051415)
φ	-0.067161*** (0.018572)	0.048792*** (0.016615)	-0.014905 (0.017373)	0.004874 (0.004001)	0.007494 (0.009749)
P_{11}	0.980723	0.979684	0.948120	0.928394	0.987389
1 - P_{11}	0.019278	0.020316	0.051880	0.071606	0.012611
P_{22}	0.961740	0.959242	0.906760	0.888004	0.941380
1 - P_{22}	0.038260	0.040758	0.093240	0.111996	0.058620
Duration 1	52	49	19	14	79
Duration 2	26	25	11	9	17
Log Likelihood	10294.56	11154.75	12869.71	17024.38	9907.293
AIC	-6.575620	-7.125437	-8.221608	-10.87720	-6.328088

*Note: *** and ** denote significance at 1 percent and 5 percent level. Standard errors are in parentheses.*

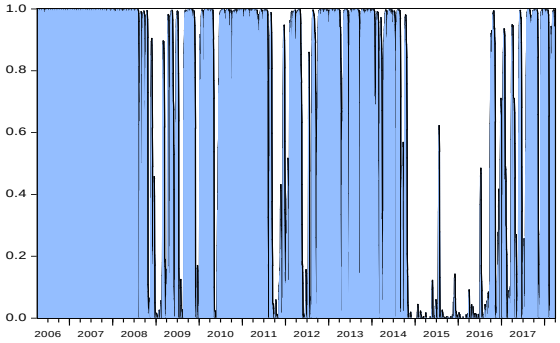
The smoothed probability curves, as shown in Figure 2.1, also support the above findings. The graphs give a clear indication of the probability of occurrence of bearish and bullish regimes and are representative of the fact that the currency markets are affected by crises, including the genesis and occurrence of global financial crisis during 2007-08, the Eurozone debt crisis in 2011, the Russian financial crisis in 2014 or the deep plunge in oil price during mid-2014 to 2016, the Brexit in 2016, the US elections in 2016, the European general elections in 2017 or the emergence of US-China trade war in 2018.

In addition, a detailed computation of the bear and bull regime cycle of the BRICS currency markets from the smoothed probabilities are presented in Appendix 2.I (Table A2.1 to Table A2.5). It is observed from the tables that Chinese Yuan has the highest number of cycles (74) followed by Indian Rupee (52), Russian Ruble (30), Brazilian Real (25) and South African Rand (17) respectively. From Figure 2.1, it can be also observed that persistence of the overall cycle is uniformly higher in bear regime than in the bull regime. The longest overall cycle (bear regime and bull regime) occurs in case of South African Rand in cycle 12 (20/06/2013 to 15/12/2015) for 629 days. Russian Ruble follows the South African currency in this regard, where the overall cycle occurs in cycle 1 (04/04/2006 to 08/08/2008) for 613 days. The longest overall cycle for Chinese Yuan in cycle 26 (05/02/2009 to 30/06/2010) is 364 days, Brazilian Real in cycle 17 (10/12/2013 to 26/05/2015) for 317 days, and Indian Rupee in cycle 24 (03/03/2011 to 09/02/2012) for 196 days. This result is in conformity with the earlier observations on persistence of cycles. The dates indicating the longest duration of cycles in Brazilian Real and South African Rand suggest that they are probably affected by the onset or aftermath of the deep plunge in oil price during mid-2014 to 2016 whereas the dates showing

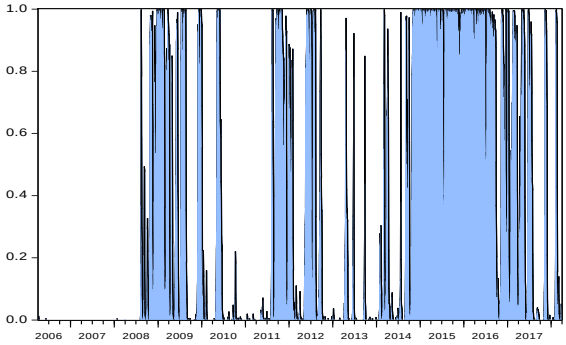
Figure 2.1: Smoothed Probability Curve of Bear and Bull Regimes



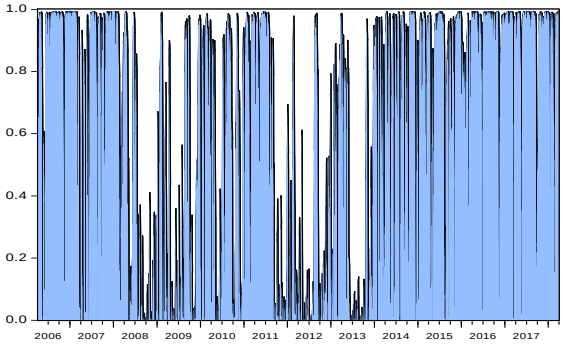
Bear Regime
Russian Ruble



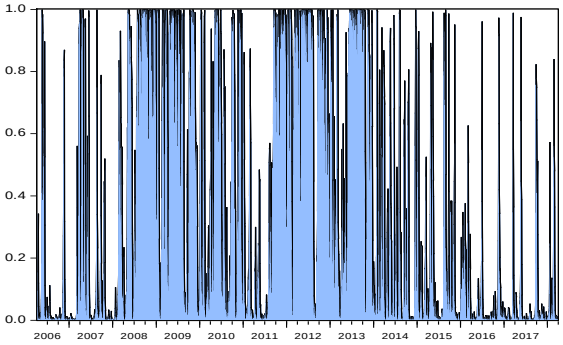
Bull Regime
Russian Ruble



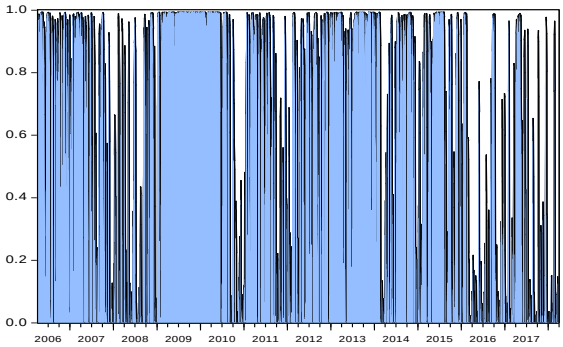
Indian Rupee



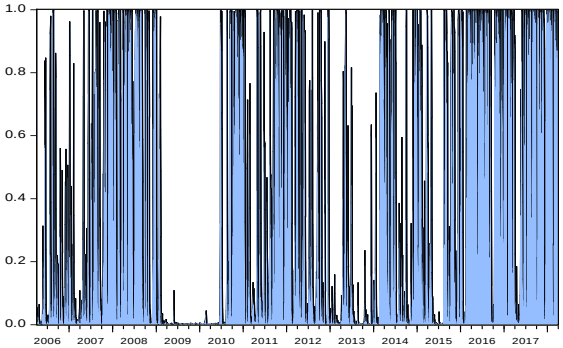
Indian Rupee



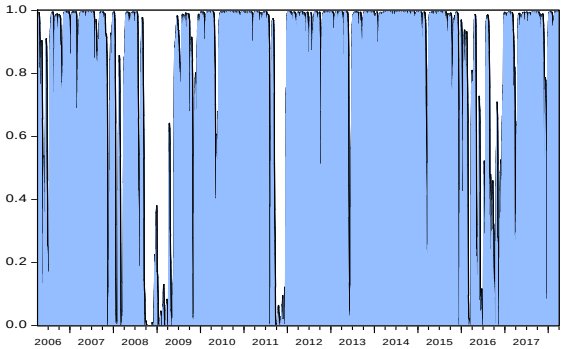
Chinese Yuan



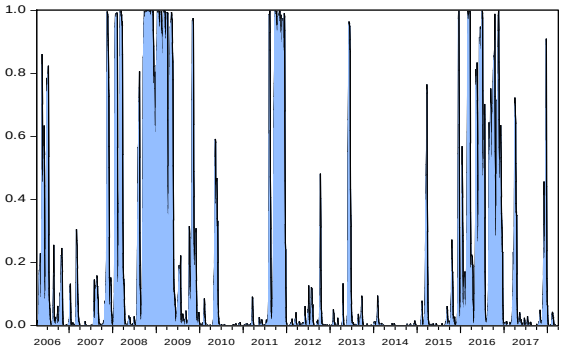
Chinese Yuan



South African Rand



South African Rand



longer duration for Russian Ruble, Chinese Yuan and Indian Rupee perhaps indicate the effect of the capital outflows from emerging markets in 2006, the global financial crisis in 2007-08 and the onset of Eurozone debt crisis in 2011. It is noteworthy that the duration of the longest overall cycle for the South African Rand and Russian Ruble is more than a year, for the Chinese Yuan and Brazilian Real, it close to a year. In contrast, it is almost half a year for the Indian Rupee.

The above results indicate that even though the mean return varies across regimes, the Chinese Yuan can be considered as the most attractive currency as it is less volatile in both the regimes. It can be noted that the low volatility of Chinese Yuan in both regimes is possibly on account of significant intervention by the monetary authorities. The South African Rand, on the other hand, is least attractive among the BRICS currencies given its high volatility in both the regimes. Moreover, the persistence of cycle in bear and bull regimes is also higher in case Chinese Yuan, which further advocates the fact of frequent intervention and changing exchange rate policies by the Chinese monetary authorities depending on the prevalent economic situation.

The existence of such cycles also shows the periods when these currencies have gone through large changes, appreciation or depreciation, normally referred to as Exchange Market Pressure, on account of shocks originating from within or outside the country or because the investors changing their portfolio holding depending on the prevailing market conditions in developed and BRICS countries. In response to such Exchange Market Pressure, the central bank often opts to intervene in the foreign exchange market to stabilize the value of the currency vis-à-vis foreign currency and maintain overall stability of the economy.

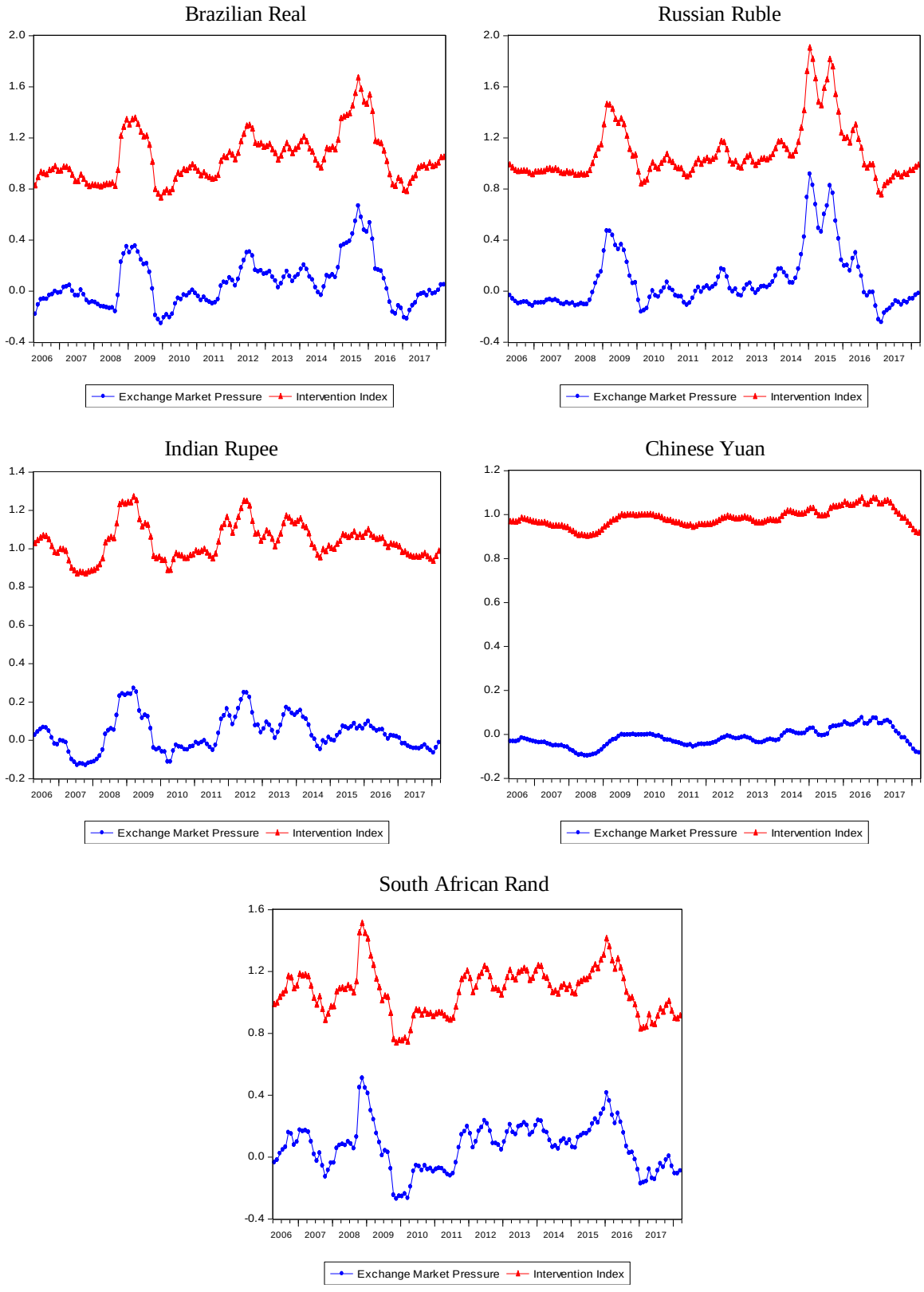
2.4.2 Exchange Market Pressure and Intervention Index: BRICS Currency Markets

This sub-section details out on Exchange Market Pressure that occurred in the BRICS foreign exchange markets and the interventions that were conducted by the respective central banks to maintain stability in the foreign exchange market during 2006-2018. The estimates of Exchange Market Pressure (EMP) and the Intervention Index for the BRICS foreign exchange markets are presented in Table A2.6 (Panel A, B) (Appendix 2.II). The Figure 2.2 depicts that Brazilian Real, Russian Ruble, Indian Rupee and South African Rand depreciated intermittently during 2008-09, 2011-12, 2013-14 and in 2015-16. On the other hand, the Chinese Yuan depreciated only after 2014, which peaked in 2016.. These phases of depreciation in the BRICS currencies correspond to the global financial crisis in 2008-09, the Eurozone Debt crisis in 2011-12, the Russian Financial crisis during 2014-17 and the deep plunge in oil price during mid-2014 to 2016.

It can also be observed that the large positive estimates of the EMP obtained during these phases indicate that these currencies were subjected to speculative attacks in times of crises. The negative estimates signify appreciation of these currencies in that particular period. It is also important to note here that the phases with downward EMP are more prominent for Brazilian Real, Russian Ruble, Indian Rupee and South African Rand than that of Chinese Yuan. This prompted the monetary authority of respective BRICS countries to intervene and restore equilibrium in the foreign exchange market.

A look at the graphs on intervention index (Figure 2.2) reveals that the respective central banks intervened during 2008-09, 2011-12, 2013-14 and in 2015-16 to counter the large depreciation of the currency. The estimated index values of more than unity are higher for South African Rand in contrast to all other currencies. This is followed by

Figure 2.2: Exchange Market Pressure and Intervention Index of BRICS Nations



Indian Rupee, Russian Ruble, Brazilian Real and Chinese Yuan. The time pattern of the estimated intervention index suggests that the central bank of China intervenes to a larger extent to maintain the exchange value of the currency with respect to US Dollar than that of Brazilian Real, Russian Ruble, Indian Rupee and South African Rand in case of any exchange market pressure. This corroborates with our finding in Figure 2.2. Moreover, the mean value of the intervention index is 1.044614, 1.080173, 1.035942, 0.983801 and 1.071473 for Brazilian Real, Russian Ruble, Indian rupee, Chinese Yuan and South African Rand respectively. These mean values suggest that whenever the central banks of Brazil, Russia, India and South Africa attempt an intervention to defend any kind of depreciation of the domestic currency, it has resulted in an appreciation of the bilateral exchange rate. However, the case with Chinese Yuan is slightly different. The mean value of intervention index for Chinese Yuan is 0.983801, which is close to 1, suggests that the central bank of China is successful in eliminating 98 per cent of the bilateral EMP during 2006-18. Such high level of intervention by the Chinese monetary authority implies that the Yuan is allowed to resettle around its free-float equilibrium value.

The evidence thus points to the behaviour of the Chinese Yuan and the fact that the Chinese monetary authority, being different from that of other BRICS nations, follows a policy of strict intervention to maintain their currency exchange value within a band and prevent it from excessive appreciation or depreciation. Since the currency market behaviour in Brazil, Russia, India and South Africa is almost similar, there is a possibility of market synchronization and portfolio diversification, which is being dealt with in the subsequent section.

2.4.3 Market Synchronization: BRICS Foreign Exchange Market

Synchronization of currency markets is the association among them and is measured by the unconditional correlation between logit transformation of the smoothed probabilities of the bull and bear regimes of the two markets. For instance, if p_{it} is the smoothed probability of market i at period t for the bear regime, then the logit transformation of such probability is as follows:

$$logit = \log\left(\frac{p_{it}}{1 - p_{it}}\right)$$

The estimates of unconditional correlation of the logit transformations, as evident from Table 2.2, range between -0.174 and 0.509 in bear regime and between -0.043 and 0.497 in bull regime. The table shows that most foreign currency markets have a positive and significant correlation among them. The exceptions to this pattern are the correlation between Chinese Yuan and Brazilian Real as well as between Chinese Yuan and Indian Rupee, with the latter being negative in both regimes and the former being insignificant in the bull regime.

It is also revealed from the table that the Indian Rupee and South African Rand are having an insignificant, although positive, correlation with Russian Ruble in bull regime. The highest correlation is between Brazilian Real and Russian Ruble in bear regime and between Brazilian Real and South African Rand in bull regime. Conversely, the correlation is lower between the Chinese Yuan and Indian Rupee in both the regimes. The magnitude and the sign of correlation coefficients signify markets synchronization and less opportunity with the investors for portfolio diversification, the exception being Chinese Yuan. This exercise thus provides an insight into the co-movements of BRICS

currencies and is indicative of the opportunity for portfolio re-allocation from the investors' point of view among the BRICS foreign exchange markets.

Table 2.2: Evidence on Currency Market Synchronization in BRICS

Bear Regime					
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
Brazilian Real	1				
Russian Ruble	0.509***	1			
Indian Rupee	0.173***	0.070***	1		
Chinese Yuan	-0.098***	0.088***	-0.174***	1	
South African Rand	0.486***	0.276***	0.058***	0.051***	1
Bull Regime					
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
Brazilian Real	1				
Russian Ruble	0.118***	1			
Indian Rupee	0.170***	0.001	1		
Chinese Yuan	-0.006	0.039**	-0.043**	1	
South African Rand	0.497***	0.018	0.099***	0.011	1

*Note: *** and ** denote significance at 1 percent and 5 percent level.*

2.5 SUMMARY OF FINDINGS

In this chapter, an attempt is being made to understand the changing pattern of volatility in BRICS currency markets. This chapter has investigated into the regime switching behaviour of the BRICS currencies in a Markov switching framework, has subsequently estimated the exchange market pressure to identify the phases of appreciation and depreciation and has constructed intervention index to show the degree of intervention by the respective central banks to mitigate the EMP. Besides, using the

smoothed probability obtained from Markov switching model. it has also shown market synchronization among the BRICS currencies.

It is found that Chinese Yuan is the least volatile among BRICS currencies in both bear and bull regimes, whereas South African Rand is the most volatile currency. The foreign exchange markets are affected by several crises, as evident from smoothed probability graphs. Besides, the persistence of the overall cycle across all foreign currency markets in BRICS countries is uniformly higher for bear regime as compared to the bull regime. In this regard, the Chinese Yuan is found to have the highest number of cycles in both bear and bull regime suggesting that the currency has gone through maximum phases of appreciation and depreciation as compared to other BRICS currencies. Moreover, the EMP estimates show that the BRICS currencies had gone through a large depreciation phase during the crises periods to which the respective central banks responded with intervention, although the degree was higher for the Chinese central bank than that in other BRICS countries. On the contrary, intervention is the least by the central bank of South Africa.

The econometric analysis has identified that the Chinese Yuan to be attractive among the BRICS currencies to the investors because of its lower volatility in both the regimes although the mean varies across regimes. On the other hand, South African Rand is observed to have a high variance in both the regimes making it unattractive for the investors. However, as is evident from the market synchronization analysis, there is less opportunity for portfolio diversification as the movements in BRICS currency markets are synchronized, with Chinese Yuan being the exception.

The essays that follow deal with BRICS currency return co-movements and volatility spillovers and the impact of economic policy uncertainty on exchange rate volatility in BRICS countries. It can be perceived that the regime changes that are observed in the BRICS currency markets can arise out of spillover effects of some crises that originated elsewhere and policy related shocks, among other factors.

APPENDIX 2.I

Table A2.1: Duration of Regimes: Brazilian Real

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
1	04/04/2006	05/05/2006	11/05/2006	02/06/2006	24	17	41
2	16/06/2006	20/07/2007	26/07/2007	29/08/2007	280	25	305
3	04/09/2007	08/11/2007	12/11/2007	28/11/2007	44	13	57
4	03/12/2007	11/01/2008	21/01/2008	24/01/2008	30	4	34
5	29/01/2008	28/02/2008	12/03/2008	19/03/2008	23	6	29
6	25/03/2008	28/08/2008	03/09/2008	07/07/2009	103	213	316
7	17/07/2009	27/07/2009	03/08/2009	18/08/2009	7	12	19
8	08/09/2009	12/10/2009	20/10/2009	02/11/2009	25	10	35
9	10/11/2009	19/01/2010	27/01/2010	04/02/2010	50	7	57
10	11/02/2010	23/04/2010	29/04/2010	10/06/2010	52	31	83
11	16/06/2010	26/07/2011	04/08/2011	10/08/2011	290	5	295
12	17/08/2011	29/08/2011	12/09/2011	13/12/2011	9	67	76
13	21/12/2011	03/05/2012	18/05/2012	03/07/2012	88	21	109
14	06/07/2012	07/06/2013	13/06/2013	21/06/2013	240	7	247
15	08/07/2013	31/07/2013	15/08/2013	18/09/2013	4	10	14
16	01/10/2013	29/10/2013	31/10/2013	31/10/2013	21	1	22
17	10/12/2013	10/09/2014	24/09/2014	26/05/2015	197	120	317
18	29/05/2015	26/06/2015	01/07/2015	08/07/2016	21	245	266
19	13/07/2016	31/08/2016	06/09/2016	16/09/2016	36	9	45
20	06/10/2016	02/11/2016	08/11/2016	10/11/2016	20	3	23
21	17/11/2016	23/02/2017	02/03/2017	15/03/2017	65	10	75
22	27/03/2017	12/05/2017	17/05/2017	19/05/2017	35	3	38
23	23/05/2017	19/10/2017	26/10/2017	30/10/2017	108	3	111
24	09/11/2017	19/01/2018	24/01/2018	24/01/2018	52	1	53
25	15/02/2018	30/03/2018	-	-	32	-	32
					1856	843	

Note: The duration of each regime was selected by sorting the smoothed probability which is above 0.80 for both Bear and Bull Regimes

Table A2.2: Duration of Regimes: Russian Ruble

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
1	04/04/2006	06/08/2008	08/08/2008	08/08/2008	612	1	613
2	18/08/2008	17/10/2008	21/10/2008	11/11/2008	39	16	55
3	17/11/2008	24/11/2008	28/11/2008	19/02/2009	6	51	57
4	24/02/2009	05/03/2009	10/03/2009	02/04/2009	8	18	26
5	06/04/2009	16/04/2009	20/04/2009	23/04/2009	9	4	13
6	29/04/2009	19/05/2009	29/05/2009	09/06/2009	15	8	23
7	16/06/2009	03/07/2009	08/07/2009	18/08/2009	14	30	44
8	20/08/2009	23/11/2009	26/11/2009	29/12/2009	68	24	92
9	04/01/2010	28/04/2010	04/05/2010	28/05/2010	82	19	101
10	16/06/2010	02/08/2011	05/08/2011	15/08/2011	294	7	301
11	19/08/2011	01/09/2011	08/09/2011	06/12/2011	10	53	63
12	09/12/2011	20/12/2011	27/12/2011	26/01/2012	8	10	18
13	01/02/2012	08/05/2012	16/05/2012	06/07/2012	70	38	108
14	11/07/2012	16/07/2012	19/07/2012	06/08/2012	4	13	17
15	08/08/2012	05/09/2012	14/09/2012	18/09/2012	21	3	24
16	28/09/2012	08/04/2013	15/04/2013	18/04/2013	137	4	141
17	01/05/2013	13/06/2013	20/06/2013	20/06/2013	32	1	33
18	24/06/2013	17/09/2013	19/09/2013	19/09/2013	62	1	63
19	23/09/2013	24/02/2014	03/03/2014	04/03/2014	103	2	105
20	06/03/2014	21/03/2014	31/03/2014	02/04/2014	12	3	15
21	09/04/2014	15/07/2014	17/07/2014	17/07/2014	70	1	71
22	21/07/2014	26/08/2014	28/08/2014	26/09/2014	27	8	35
23	01/10/2014	16/10/2014	23/10/2014	21/09/2016	12	486	498
24	27/09/2016	02/11/2016	04/11/2016	05/01/2017	27	25	52
25	12/01/2017	24/01/2017	09/02/2017	17/03/2017	9	27	36
26	22/03/2017	05/04/2017	21/04/2017	19/05/2017	11	17	28
27	24/05/2017	13/06/2017	19/06/2017	14/07/2017	15	14	29
28	26/07/2017	01/11/2017	03/11/2017	20/11/2017	71	12	83
29	24/11/2017	31/01/2018	02/02/2018	14/02/2018	49	9	58
30	16/02/2018	30/03/2018	-	-	31	-	31
					1928	905	

Note: The duration of each regime was selected by sorting the smoothed probability which is above 0.80 for both Bear and Bull Regimes

Table A2.3: Duration of Regimes: Indian Rupee

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
1	04/04/2006	10/05/2006	15/05/2006	02/06/2006	26	5	31
2	07/06/2006	08/11/2006	14/11/2006	16/11/2006	111	3	114
3	20/11/2006	16/03/2007	20/03/2007	02/04/2007	82	10	92
4	05/04/2007	11/04/2007	13/04/2007	25/04/2007	5	9	14
5	01/05/2007	03/05/2007	10/05/2007	14/05/2007	3	3	6
6	17/05/2007	28/05/2007	08/06/2007	11/06/2007	8	2	10
7	14/06/2007	13/08/2007	16/08/2007	16/08/2007	43	1	44
8	23/08/2007	14/02/2008	20/02/2008	03/03/2008	117	3	120
9	20/03/2008	25/04/2008	06/05/2008	03/06/2008	25	21	46
10	11/06/2008	10/07/2008	23/07/2008	20/01/2009	22	104	126
11	23/01/2009	11/02/2009	17/02/2009	02/04/2009	14	19	33
12	08/04/2009	14/04/2009	20/04/2009	17/08/2009	5	68	73
13	19/08/2009	29/09/2009	02/10/2009	19/11/2009	25	29	54
14	09/12/2009	30/12/2009	04/01/2010	12/01/2010	16	7	23
15	15/01/2010	26/01/2010	03/02/2010	05/02/2010	8	3	11
16	10/02/2010	25/03/2010	05/04/2010	05/04/2010	29	1	30
17	08/04/2010	15/04/2010	19/04/2010	19/04/2010	6	1	7
18	22/04/2010	27/04/2010	05/05/2010	24/06/2010	4	31	35
19	05/07/2010	14/07/2010	19/07/2010	20/07/2010	8	2	10
20	02/08/2010	15/09/2010	24/09/2010	14/10/2010	30	15	45
21	26/10/2010	10/11/2010	12/11/2010	15/12/2010	12	16	28
22	22/12/2010	29/12/2010	04/01/2011	05/01/2011	6	2	8
23	12/01/2011	16/02/2011	22/02/2011	24/02/2011	26	3	29
24	03/03/2011	31/08/2011	09/09/2011	09/02/2012	110	86	196
25	15/02/2012	23/02/2012	01/03/2012	08/08/2012	7	105	112
26	13/08/2012	10/09/2012	14/09/2012	18/01/2013	19	59	78
27	23/01/2013	07/02/2013	21/02/2013	01/03/2013	7	7	14
28	11/03/2013	03/05/2013	10/05/2013	10/05/2013	26	1	27
29	14/05/2013	23/05/2013	30/05/2013	17/10/2013	7	101	108
30	22/10/2013	31/10/2013	06/11/2013	16/12/2013	8	19	27
31	19/12/2013	20/01/2014	24/01/2014	28/01/2014	23	3	26
32	31/01/2014	10/02/2014	14/02/2014	14/02/2014	7	1	8
33	19/02/2014	28/02/2014	06/03/2014	06/03/2014	8	1	9

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
34	13/03/2014	17/03/2014	20/03/2014	25/03/2014	3	4	7
35	01/04/2014	09/05/2014	15/05/2014	16/05/2014	24	2	26
36	28/05/2014	11/06/2014	13/06/2014	18/06/2014	11	4	15
37	23/06/2014	29/07/2014	31/07/2014	06/08/2014	22	4	26
38	12/08/2014	07/10/2014	16/10/2014	16/10/2014	28	1	29
39	21/10/2014	09/12/2014	15/12/2014	18/12/2014	36	4	40
40	23/12/2014	29/12/2014	07/01/2015	08/01/2015	5	2	7
41	13/01/2015	16/04/2015	20/04/2015	23/04/2015	59	3	62
42	30/04/2015	04/05/2015	07/05/2015	08/05/2015	3	2	5
43	18/05/2015	07/08/2015	11/08/2015	25/08/2015	60	7	67
44	01/09/2015	16/09/2015	18/09/2015	18/09/2015	12	1	13
45	23/09/2015	30/10/2015	09/11/2015	09/11/2015	23	1	24
46	11/11/2015	21/06/2016	24/06/2016	24/06/2016	143	1	144
47	28/06/2016	08/11/2016	11/11/2016	15/11/2015	96	3	99
48	22/11/2016	10/03/2017	14/03/2017	14/03/2017	79	1	80
49	17/03/2017	15/05/2017	18/05/2017	18/05/2017	42	1	43
50	24/05/2017	19/09/2017	21/09/2017	21/09/2017	85	1	86
51	06/10/2017	14/02/2018	20/02/2018	20/02/2018	91	1	92
52	26/02/2018	30/03/2018	-	-	25	-	25
					1700	784	

Note: The duration of each regime was selected by sorting the smoothed probability which is above 0.80 for both Bear and Bull Regimes

Table A2.4: Duration of Regimes: Chinese Yuan

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
1	04/04/2006	01/06/2006	05/06/2006	13/06/2006	41	2	43
2	15/06/2006	17/07/2007	21/07/2006	24/07/2006	23	2	25
3	28/07/2006	10/08/2006	14/08/2006	17/08/2006	10	4	14
4	22/08/2006	31/08/2006	04/09/2006	04/09/2006	8	1	9
5	08/09/2006	27/12/2006	29/12/2006	02/01/2007	61	3	64
6	15/01/2007	30/01/2007	01/02/2007	01/02/2007	11	1	12
7	05/02/2007	23/04/2007	26/04/2007	30/04/2007	56	3	59
8	02/05/2007	01/06/2007	07/06/2007	13/06/2007	21	5	26
9	15/06/2007	29/06/2007	10/07/2007	11/07/2007	11	2	13
10	16/07/2007	24/07/2007	03/08/2007	24/08/2007	7	12	19
11	29/08/2007	04/09/2007	10/09/2007	10/09/2007	5	1	6
12	14/09/2007	08/10/2007	15/10/2007	15/10/2007	17	1	18
13	19/10/2007	19/10/2007	24/10/2007	14/11/2007	1	12	13
14	16/11/2007	22/11/2007	27/11/2007	28/01/2008	5	35	40
15	01/02/2008	11/02/2008	13/02/2008	28/02/2008	7	12	19
16	04/03/2008	13/03/2008	19/03/2008	27/03/2008	8	7	15
17	31/03/2008	03/04/2008	07/04/2008	29/04/2008	4	15	19
18	01/05/2008	06/05/2008	08/05/2008	06/06/2008	4	22	26
19	20/06/2008	01/07/2008	04/07/2008	02/09/2008	8	38	46
20	08/09/2008	19/09/2008	23/09/2008	26/09/2008	10	4	14
21	30/09/2008	03/10/2008	07/10/2008	13/10/2008	4	5	9
22	16/10/2008	22/10/2008	27/10/2008	29/10/2008	5	3	8
23	31/10/2008	27/11/2008	01/12/2008	01/12/2008	20	1	21
24	04/12/2008	05/12/2008	10/12/2008	30/12/2008	2	15	17
25	01/01/2009	21/01/2009	29/01/2009	30/01/2009	15	2	17
26	05/02/2009	17/06/2010	21/06/2010	30/06/2010	356	8	364
27	06/07/2010	10/08/2010	12/08/2010	17/08/2010	26	4	30
28	19/08/2010	02/09/2010	06/09/2010	22/09/2010	10	13	23
29	24/09/2010	30/09/2010	13/10/2010	13/01/2011	5	52	57
30	17/01/2011	20/04/2011	22/04/2011	29/04/2011	60	6	66
31	03/05/2011	13/05/2011	20/05/2011	24/05/2011	9	3	12
32	26/05/2011	15/06/2011	21/06/2011	21/06/2011	15	1	16
33	30/06/2011	05/08/2011	10/08/2011	11/08/2011	22	2	24

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
34	25/08/2011	05/09/2011	08/09/2011	12/09/2011	8	3	11
35	19/09/2011	21/09/2011	26/09/2011	01/12/2011	3	33	36
36	06/12/2011	13/12/2011	16/12/2011	08/02/2012	6	22	28
37	10/02/2012	02/03/2012	12/03/2012	12/03/2012	16	1	17
38	15/03/2012	20/03/2012	22/03/2012	06/04/2012	4	10	14
39	11/04/2012	11/04/2012	16/04/2012	17/04/2012	1	2	3
40	19/04/2012	26/04/2012	30/04/2012	02/05/2012	6	2	8
41	04/05/2012	21/05/2012	23/05/2012	31/05/2012	9	4	13
42	05/06/2012	26/07/2012	31/07/2012	31/07/2012	28	1	29
43	06/08/2012	10/09/2012	14/09/2012	14/09/2012	26	1	27
44	24/09/2012	25/09/2012	28/09/2012	28/09/2012	2	1	3
45	02/10/2012	08/10/2012	10/10/2012	12/10/2012	5	3	8
46	19/10/2012	08/11/2012	12/11/2012	12/11/2012	15	1	16
47	16/11/2012	06/12/2012	10/12/2012	17/12/2012	15	6	21
48	19/12/2012	12/04/2013	17/04/2013	17/04/2013	83	1	84
49	22/04/2013	30/04/2013	02/05/2013	10/05/2013	7	7	14
50	15/05/2013	20/06/2013	24/06/2013	24/06/2013	24	1	25
51	02/07/2013	17/02/2014	19/02/2014	24/04/2014	157	34	191
52	28/04/2014	01/05/2014	05/05/2014	12/05/2014	4	6	10
53	14/05/2014	23/05/2014	27/05/2014	16/06/2014	8	4	12
54	19/06/2014	23/06/2014	26/06/2014	02/07/2014	3	5	8
55	07/07/2014	24/09/2014	26/09/2014	30/09/2014	48	3	51
56	02/10/2014	19/11/2014	24/11/2014	24/11/2014	34	1	35
57	27/11/2014	03/12/2014	08/12/2014	05/01/2015	5	14	19
58	08/01/2015	12/01/2015	15/01/2015	04/02/2015	3	12	15
59	11/02/2015	13/03/2015	17/03/2015	25/03/2015	20	7	27
60	01/04/2015	21/04/2015	27/04/2015	28/04/2015	15	2	17
61	01/05/2015	07/08/2015	11/08/2015	09/09/2015	71	13	84
62	11/09/2015	07/10/2015	09/10/2015	09/11/2015	15	17	32
63	12/11/2015	03/12/2015	08/12/2015	17/12/2015	15	8	23
64	21/12/2015	25/12/2015	04/01/2016	14/01/2016	5	9	14
65	19/01/2016	11/02/2016	15/02/2016	09/09/2016	18	118	136
66	13/09/2016	06/10/2016	10/10/2016	25/01/2017	18	56	74
67	27/01/2017	01/02/2017	03/02/2017	03/03/2017	4	18	22
68	10/03/2017	14/03/2017	16/03/2017	29/03/2017	3	8	11

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
69	31/03/2017	12/05/2017	25/05/2017	01/06/2017	31	6	37
70	07/06/2017	13/06/2017	15/06/2017	03/07/2017	5	9	14
71	05/07/2017	10/07/2017	12/07/2017	28/09/2017	4	52	56
72	03/10/2017	05/10/2017	09/10/2017	30/11/2017	3	33	36
73	05/12/2017	13/12/2017	18/12/2017	13/02/2018	7	42	49
74	15/02/2018	20/02/2018	22/02/2018	30/03/2018	4	27	31
					1625	900	

Note: The duration of each regime was selected by sorting the smoothed probability which is above 0.80 for both Bear and Bull Regimes

Table A2.5: Duration of Regime: South African Rand

Cycle	Bull and Bear Regimes for each				Duration of Regimes (in days)		Total Duration (in days)
	Bear Regime		Bull Regime		Bear	Bull	
1	04/04/2006	08/05/2006	12/05/2006	15/06/2006	24	2	26
2	07/06/2006	15/06/2006	03/07/2006	05/07/2006	7	3	10
3	10/07/2006	05/11/2007	09/11/2007	21/11/2007	335	8	343
4	30/11/2007	10/01/2008	16/01/2008	05/02/2008	30	15	45
5	12/02/2008	18/02/2008	27/02/2008	19/03/2008	5	16	21
6	25/03/2008	22/07/2008	08/08/2008	08/08/2008	86	1	87
7	13/08/2008	02/09/2008	10/09/2008	15/05/2009	15	151	166
8	22/05/2009	20/10/2009	27/10/2009	04/11/2009	104	7	111
9	18/11/2009	29/07/2011	04/08/2011	10/08/2011	415	5	420
10	18/08/2011	07/09/2011	16/09/2011	12/12/2011	15	62	77
11	21/12/2011	24/05/2013	30/05/2013	13/06/2013	369	11	380
12	20/06/2013	04/12/2015	09/12/2015	15/12/2015	624	5	629
13	21/12/2015	16/02/2016	24/02/2016	17/03/2016	34	17	51
14	24/03/2016	29/04/2016	04/05/2016	29/06/2016	22	21	43
15	20/07/2016	18/08/2016	28/09/2016	14/11/2016	22	17	39
16	15/12/2016	22/11/2017	15/12/2017	18/12/2017	228	2	230
17	21/12/2017	30/03/2018	-	-	72	-	72
					2407	343	

Note: The duration of each regime was selected by sorting the smoothed probability which is above 0.80 for both Bear and Bull Regimes

Appendix 2.II

Table A2.6: Exchange Market Pressure and Intervention Index: BRICS Foreign Exchange Markets

Year	Panel A Exchange Market Pressure					Panel B Intervention Index				
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
2006-04-01	-0.180658	-0.032741	0.027883	-0.031640	-0.034722	0.826017	0.990323	1.027841	0.968341	0.988083
2006-05-01	-0.106513	-0.060087	0.043106	-0.031702	-0.019061	0.890379	0.967583	1.04305	0.968279	0.99768
2006-06-01	-0.065552	-0.080635	0.057359	-0.032727	0.023379	0.931064	0.946191	1.057301	0.967255	1.035258
2006-07-01	-0.060749	-0.096960	0.067406	-0.027947	0.046228	0.92223	0.937536	1.067352	0.972036	1.057562
2006-08-01	-0.063817	-0.090656	0.065051	-0.015856	0.064681	0.913202	0.939553	1.065003	0.984128	1.07662
2006-09-01	-0.032512	-0.085031	0.048452	-0.019574	0.158478	0.945203	0.942402	1.048401	0.98041	1.169897
2006-10-01	-0.025307	-0.086053	0.013144	-0.023160	0.149729	0.951628	0.940676	1.01309	0.976824	1.16038
2006-11-01	-0.001388	-0.104753	-0.019097	-0.027270	0.078370	0.975912	0.924596	0.980829	0.972712	1.090115
2006-12-01	-0.013542	-0.115261	-0.021756	-0.031389	0.097376	0.94002	0.913012	0.978145	0.968594	1.107919
2007-01-01	-0.011081	-0.091883	-0.001755	-0.034213	0.174843	0.942032	0.934268	0.998148	0.96577	1.183144
2007-02-01	0.030426	-0.093074	-0.003652	-0.037221	0.166661	0.971054	0.932604	0.996223	0.962759	1.173657
2007-03-01	0.035075	-0.090670	-0.011996	-0.036810	0.171500	0.970125	0.936867	0.987896	0.963169	1.178382
2007-04-01	0.045279	-0.088979	-0.061575	-0.036051	0.162997	0.954775	0.938003	0.938332	0.963926	1.168057
2007-05-01	-0.000021	-0.072001	-0.099710	-0.042071	0.100256	0.9097	0.955	0.900195	0.957906	1.107879
2007-06-01	-0.033658	-0.066132	-0.114213	-0.046601	0.019066	0.86089	0.960222	0.88568	0.953375	1.027166
2007-07-01	-0.036148	-0.075065	-0.129623	-0.051991	-0.024884	0.859518	0.949049	0.870245	0.947983	0.985308
2007-08-01	0.008655	-0.067477	-0.121146	-0.050049	0.026660	0.91064	0.958051	0.878723	0.949925	1.037031
2007-09-01	-0.028053	-0.079664	-0.123733	-0.051753	-0.055356	0.87671	0.945482	0.876095	0.948221	0.955084
2007-10-01	-0.072625	-0.100556	-0.129822	-0.050552	-0.127319	0.837921	0.926271	0.869979	0.949423	0.885464
2007-11-01	-0.092389	-0.105274	-0.119871	-0.056260	-0.085145	0.819427	0.920045	0.879935	0.943715	0.926888
2007-12-01	-0.083091	-0.089102	-0.115603	-0.058050	-0.038777	0.831127	0.934964	0.884208	0.941925	0.973615
2008-01-01	-0.087866	-0.100597	-0.111175	-0.069991	-0.037239	0.82973	0.924641	0.888611	0.929984	0.974328
2008-02-01	-0.104416	-0.092596	-0.099482	-0.075445	0.057034	0.824935	0.931198	0.900332	0.924531	1.069431

Year	Panel A Exchange Market Pressure					Panel B Intervention Index				
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
2008-03-01	-0.120381	-0.112496	-0.082156	-0.085980	0.076006	0.818805	0.908707	0.917656	0.913997	1.088416
2008-04-01	-0.123018	-0.108043	-0.050852	-0.093986	0.082898	0.829809	0.910329	0.948965	0.905991	1.094583
2008-05-01	-0.127898	-0.096307	0.031597	-0.091598	0.076002	0.83713	0.918258	1.031423	0.90838	1.085785
2008-06-01	-0.134954	-0.104506	0.050602	-0.096109	0.099377	0.836771	0.911993	1.050445	0.90387	1.108999
2008-07-01	-0.131164	-0.103298	0.060221	-0.097490	0.085755	0.845181	0.914567	1.060104	0.902491	1.09341
2008-08-01	-0.157608	-0.071007	0.053833	-0.095120	0.056571	0.821207	0.945529	1.053735	0.904861	1.062781
2008-09-01	-0.032208	-0.011655	0.130306	-0.091034	0.129689	0.947065	1.001111	1.130254	0.908947	1.134929
2008-10-01	0.226948	0.060840	0.230715	-0.088807	0.449124	1.213296	1.064271	1.230731	0.911177	1.451188
2008-11-01	0.292285	0.118326	0.242574	-0.079664	0.510435	1.284557	1.117428	1.242606	0.920321	1.511636
2008-12-01	0.348819	0.151403	0.234199	-0.069611	0.447544	1.343028	1.146507	1.234223	0.930373	1.449015
2009-01-01	0.302331	0.313635	0.241842	-0.055923	0.412209	1.302081	1.304569	1.241895	0.944066	1.412392
2009-02-01	0.340919	0.471409	0.240854	-0.045840	0.301160	1.343343	1.46166	1.240914	0.954151	1.300622
2009-03-01	0.352768	0.468772	0.271230	-0.033415	0.242199	1.354693	1.457875	1.271294	0.966576	1.241857
2009-04-01	0.305369	0.437358	0.252050	-0.023911	0.153409	1.307451	1.425253	1.252119	0.976081	1.153
2009-05-01	0.245049	0.358226	0.153759	-0.021322	0.096002	1.246127	1.34686	1.153817	0.978669	1.097525
2009-06-01	0.209521	0.327071	0.115154	-0.009344	0.010285	1.209274	1.315148	1.115207	0.990646	1.011475
2009-07-01	0.215315	0.363856	0.130881	-0.000661	0.040841	1.21387	1.34975	1.13092	0.999329	1.041766
2009-08-01	0.148358	0.319283	0.123912	-0.003022	0.030533	1.144376	1.306341	1.123935	0.996968	1.034991
2009-09-01	0.016717	0.224966	0.061621	-0.001332	-0.075096	1.011057	1.213612	1.061629	0.998656	0.93094
2009-10-01	-0.189997	0.117187	-0.039090	-0.001260	-0.246009	0.796766	1.112083	0.960871	0.998726	0.762221
2009-11-01	-0.222392	0.060829	-0.049679	-0.000247	-0.269725	0.760974	1.059166	0.950279	0.999737	0.73877
2009-12-01	-0.251651	0.066037	-0.042616	-0.003932	-0.252571	0.730461	1.066532	0.95736	0.996054	0.754085
2010-01-01	-0.207246	-0.071007	-0.059717	-0.001668	-0.253598	0.771134	0.9337	0.94025	0.998316	0.75381
2010-02-01	-0.185121	-0.162684	-0.060378	-0.001228	-0.237766	0.792352	0.842415	0.939592	0.998757	0.769572
2010-03-01	-0.206905	-0.151245	-0.112340	-0.001483	-0.265121	0.771345	0.854993	0.887633	0.998502	0.745133
2010-04-01	-0.180271	-0.136448	-0.111853	-0.000834	-0.191045	0.796669	0.871135	0.888121	0.999152	0.819169

Year	Panel A Exchange Market Pressure					Panel B Intervention Index				
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
2010-05-01	-0.100301	-0.048673	-0.055628	0.000510	-0.091538	0.878022	0.955802	0.944369	1.0005	0.915503
2010-06-01	-0.055905	0.001331	-0.025177	-0.002185	-0.054682	0.924261	1.005225	0.974821	0.997806	0.95251
2010-07-01	-0.065376	-0.035533	-0.033309	-0.008102	-0.060570	0.915967	0.971287	0.966687	0.991888	0.948239
2010-08-01	-0.030426	-0.046007	-0.036343	-0.006515	-0.086184	0.95324	0.959846	0.963662	0.993476	0.918944
2010-09-01	-0.036891	-0.005173	-0.049284	-0.012785	-0.055520	0.944405	1.001547	0.950714	0.987205	0.949066
2010-10-01	-0.014525	0.024344	-0.049608	-0.023449	-0.079247	0.96746	1.029335	0.950388	0.97654	0.924669
2010-11-01	0.007071	0.068645	-0.033979	-0.025523	-0.073248	0.991081	1.071001	0.96602	0.974468	0.929299
2010-12-01	-0.017501	0.021586	-0.031774	-0.026305	-0.093738	0.966278	1.024273	0.968213	0.973684	0.909909
2011-01-01	-0.041339	0.005685	-0.011816	-0.033169	-0.078007	0.940224	1.009428	0.988166	0.966819	0.928279
2011-02-01	-0.072730	-0.034819	-0.019628	-0.035805	-0.072342	0.905917	0.969675	0.980347	0.964181	0.936025
2011-03-01	-0.048101	-0.042895	-0.011871	-0.038108	-0.074151	0.92857	0.96124	0.988102	0.961878	0.932867
2011-04-01	-0.073668	-0.043703	-0.002706	-0.043462	-0.092731	0.901015	0.960844	0.997257	0.956523	0.915222
2011-05-01	-0.085268	-0.089591	-0.020742	-0.048644	-0.111787	0.888914	0.915364	0.979214	0.951339	0.896394
2011-06-01	-0.097406	-0.109482	-0.037237	-0.050437	-0.120812	0.877242	0.895413	0.962716	0.949545	0.887163
2011-07-01	-0.090249	-0.092665	-0.051637	-0.046982	-0.105882	0.883017	0.91125	0.948327	0.953002	0.900057
2011-08-01	-0.065406	-0.056546	-0.026322	-0.056484	-0.035827	0.907334	0.948036	0.973638	0.9435	0.971047
2011-09-01	0.039579	-0.002077	0.035943	-0.052033	0.061259	1.018592	0.999208	1.035929	0.947955	1.066273
2011-10-01	0.069646	0.029937	0.109340	-0.044964	0.144771	1.051172	1.031119	1.109323	0.955025	1.149863
2011-11-01	0.063987	-0.006393	0.128285	-0.044578	0.164497	1.045919	0.994895	1.128272	0.955413	1.170192
2011-12-01	0.104679	0.023786	0.164261	-0.045193	0.197886	1.087592	1.024757	1.164266	0.9548	1.202951
2012-01-01	0.082971	0.039975	0.127231	-0.043554	0.151449	1.068083	1.040508	1.127244	0.95644	1.156173
2012-02-01	0.042173	0.017283	0.082638	-0.043097	0.060770	1.029911	1.017806	1.082651	0.956897	1.064001
2012-03-01	0.093133	0.032809	0.120287	-0.038458	0.099674	1.08139	1.032828	1.120303	0.961537	1.100147
2012-04-01	0.182916	0.051418	0.165531	-0.034525	0.167958	1.171976	1.050836	1.165555	0.965473	1.166825
2012-05-01	0.239168	0.108701	0.210641	-0.026401	0.191203	1.229962	1.107402	1.210672	0.973598	1.18987
2012-06-01	0.301191	0.174039	0.249095	-0.017169	0.235386	1.29237	1.172664	1.249126	0.98283	1.234325

Year	Panel A Exchange Market Pressure					Panel B Intervention Index				
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
2012-07-01	0.305420	0.166432	0.247953	-0.013489	0.215593	1.298665	1.164026	1.247986	0.986512	1.214847
2012-08-01	0.275867	0.111380	0.224225	-0.006974	0.168539	1.270574	1.108742	1.224257	0.993026	1.167748
2012-09-01	0.164479	0.019794	0.143347	-0.010776	0.088196	1.158076	1.020136	1.143365	0.989222	1.088845
2012-10-01	0.152470	-0.003644	0.076787	-0.015998	0.088892	1.14722	0.996208	1.076812	0.984002	1.08939
2012-11-01	0.160681	0.015559	0.079709	-0.019415	0.077828	1.155228	1.016776	1.079724	0.980583	1.078949
2012-12-01	0.133149	-0.030059	0.040606	-0.017912	0.047935	1.128901	0.972928	1.040607	0.982085	1.049373
2013-01-01	0.138264	-0.037426	0.059435	-0.014208	0.097694	1.134615	0.964727	1.05943	0.985789	1.097715
2013-02-01	0.153016	0.014239	0.094056	-0.010547	0.162363	1.149541	1.015299	1.094059	0.989451	1.161644
2013-03-01	0.109426	0.049452	0.079788	-0.015463	0.209857	1.107279	1.050487	1.079789	0.984535	1.209446
2013-04-01	0.080049	0.061960	0.050559	-0.018485	0.160120	1.079424	1.062823	1.050556	0.981511	1.161458
2013-05-01	0.027814	0.011916	0.010854	-0.028924	0.147740	1.027672	1.012654	1.010847	0.971071	1.147612
2013-06-01	0.059044	-0.014576	0.042177	-0.036044	0.196245	1.060172	0.986066	1.04218	0.963952	1.195126
2013-07-01	0.108286	0.008324	0.077815	-0.037181	0.204011	1.109375	1.009074	1.077823	0.962814	1.20331
2013-08-01	0.154578	0.033630	0.131963	-0.037429	0.221725	1.156943	1.033572	1.131976	0.962566	1.220749
2013-09-01	0.115934	0.037847	0.171092	-0.031847	0.205028	1.118182	1.038114	1.171105	0.968146	1.205907
2013-10-01	0.076421	0.029627	0.161061	-0.025684	0.142933	1.079151	1.030063	1.161069	0.974309	1.144079
2013-11-01	0.108131	0.044256	0.141378	-0.022405	0.158360	1.111257	1.044143	1.141374	0.977587	1.159098
2013-12-01	0.126635	0.071637	0.131016	-0.025559	0.203992	1.129434	1.070188	1.131009	0.974432	1.204856
2014-01-01	0.170926	0.119448	0.144451	-0.027587	0.238029	1.173354	1.117459	1.144448	0.972405	1.237959
2014-02-01	0.204022	0.170944	0.155494	-0.024454	0.232701	1.206216	1.168593	1.155482	0.975537	1.233619
2014-03-01	0.169468	0.174696	0.120620	-0.006809	0.168142	1.172031	1.171693	1.120599	0.993183	1.168923
2014-04-01	0.112310	0.143703	0.110156	0.006129	0.158592	1.114697	1.138715	1.110131	1.006122	1.158439
2014-05-01	0.088009	0.116055	0.079685	0.015853	0.108808	1.089122	1.111699	1.079652	1.015845	1.110818
2014-06-01	0.028684	0.066500	0.023672	0.015798	0.064681	1.027859	1.062716	1.023628	1.01579	1.066416
2014-07-01	-0.010827	0.064636	0.005427	0.010628	0.072582	0.98815	1.060433	1.005373	1.010621	1.075311
2014-08-01	-0.031263	0.099513	-0.032368	0.005383	0.053559	0.966098	1.095488	0.967575	1.005376	1.055876

Year	Panel A Exchange Market Pressure					Panel B Intervention Index				
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
2014-09-01	0.032026	0.173185	-0.046182	0.003168	0.102073	1.030516	1.167098	0.953768	1.003165	1.101619
2014-10-01	0.120824	0.285536	-0.003384	0.003537	0.116902	1.118322	1.277146	0.99657	1.003536	1.115999
2014-11-01	0.112340	0.422528	-0.014045	0.005460	0.087448	1.109504	1.413666	0.985922	1.00546	1.086873
2014-12-01	0.128982	0.732907	0.014976	0.019228	0.110345	1.127949	1.721383	1.014943	1.019227	1.109763
2015-01-01	0.106751	0.916141	0.001932	0.027594	0.064939	1.106575	1.90432	1.001886	1.027595	1.063075
2015-02-01	0.184204	0.829199	-0.002203	0.028186	0.059910	1.184184	1.816669	0.997744	1.028188	1.057381
2015-03-01	0.351300	0.676947	0.024606	0.010669	0.126878	1.351504	1.664401	1.024561	1.010672	1.124224
2015-04-01	0.363467	0.492613	0.039237	-0.003678	0.139135	1.363893	1.480937	1.039189	0.996325	1.136903
2015-05-01	0.376233	0.464017	0.073719	-0.005558	0.153046	1.376654	1.452753	1.073673	0.994446	1.150294
2015-06-01	0.390523	0.600206	0.068297	-0.004089	0.151623	1.391472	1.588795	1.068252	0.995915	1.150248
2015-07-01	0.448079	0.666696	0.059667	0.001511	0.171851	1.449762	1.655882	1.059628	1.001516	1.168571
2015-08-01	0.547574	0.824882	0.070024	0.029983	0.214614	1.54977	1.814913	1.069985	1.029989	1.211607
2015-09-01	0.667039	0.765762	0.087733	0.037346	0.246094	1.669936	1.756943	1.087691	1.037351	1.243469
2015-10-01	0.578545	0.548330	0.059780	0.036580	0.223272	1.581565	1.541367	1.059737	1.036584	1.220742
2015-11-01	0.477590	0.410515	0.072582	0.039889	0.278325	1.481361	1.404218	1.072543	1.039895	1.275219
2015-12-01	0.462797	0.242501	0.060161	0.042485	0.309364	1.464254	1.240109	1.060126	1.042492	1.306748
2016-01-01	0.535445	0.196835	0.082463	0.056480	0.415065	1.536296	1.19595	1.082439	1.056489	1.41311
2016-02-01	0.406497	0.202179	0.099426	0.047471	0.363476	1.407188	1.203484	1.099414	1.04748	1.361885
2016-03-01	0.173247	0.159418	0.071527	0.042576	0.271312	1.174355	1.162077	1.071508	1.042584	1.27146
2016-04-01	0.166540	0.255275	0.060008	0.044424	0.217948	1.167078	1.258421	1.059997	1.044432	1.217267
2016-05-01	0.156560	0.300039	0.049870	0.052964	0.283382	1.157253	1.302849	1.049862	1.052972	1.282753
2016-06-01	0.098015	0.187879	0.054136	0.062149	0.225559	1.099036	1.189989	1.05413	1.062156	1.224346
2016-07-01	0.017230	0.117529	0.055808	0.075840	0.156734	1.017116	1.119752	1.055799	1.075847	1.155965
2016-08-01	-0.086297	-0.012085	0.028070	0.048931	0.069428	0.913489	0.989458	1.028059	1.048937	1.068228
2016-09-01	-0.164171	-0.037174	0.008281	0.047731	0.026695	0.833972	0.964097	1.008262	1.047736	1.026935
2016-10-01	-0.176426	-0.009510	0.025399	0.060054	0.030878	0.822276	0.991434	1.025389	1.060061	1.031299

Year	Panel A Exchange Market Pressure					Panel B Intervention Index				
	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand
2016-11-01	-0.113991	-0.009557	0.021834	0.074675	-0.015747	0.884198	0.991309	1.021826	1.074681	0.985685
2016-12-01	-0.134389	-0.116441	0.019708	0.072854	-0.079968	0.863789	0.883261	1.019701	1.07286	0.921027
2017-01-01	-0.208120	-0.222564	0.011544	0.049636	-0.170737	0.789704	0.778404	1.011532	1.04964	0.830482
2017-02-01	-0.215898	-0.244772	-0.017545	0.049289	-0.165182	0.782027	0.756152	0.98244	1.049292	0.835741
2017-03-01	-0.150666	-0.172347	-0.016203	0.060144	-0.157102	0.846632	0.827838	0.983788	1.060148	0.842635
2017-04-01	-0.113613	-0.150422	-0.029360	0.063657	-0.078489	0.88363	0.849744	0.970631	1.06366	0.921534
2017-05-01	-0.091169	-0.135121	-0.037224	0.053944	-0.137302	0.906055	0.865715	0.962758	1.053947	0.863812
2017-06-01	-0.032787	-0.108127	-0.042194	0.032936	-0.143738	0.964386	0.893666	0.957784	1.032939	0.857708
2017-07-01	-0.021572	-0.076131	-0.040791	0.013897	-0.088217	0.975921	0.926267	0.959182	1.0139	0.912765
2017-08-01	-0.014807	-0.087386	-0.043936	0.002930	-0.042335	0.982599	0.915127	0.956033	1.002932	0.959045
2017-09-01	-0.034323	-0.106593	-0.034365	-0.015308	-0.063711	0.96338	0.895773	0.965608	0.984693	0.938752
2017-10-01	0.005120	-0.080484	-0.024782	-0.015550	-0.017928	1.002397	0.922678	0.975186	0.984451	0.984103
2017-11-01	-0.020760	-0.089133	-0.040752	-0.032841	0.005512	0.97598	0.914961	0.959209	0.967158	1.008534
2017-12-01	-0.013337	-0.059708	-0.053188	-0.048034	-0.058719	0.984815	0.945335	0.946765	0.951964	0.944296
2018-01-01	0.006434	-0.058687	-0.065344	-0.067429	-0.105179	1.004799	0.946347	0.9346	0.932568	0.898314
2018-02-01	0.049006	-0.031618	-0.038680	-0.079908	-0.106424	1.047331	0.973737	0.961266	0.92009	0.896841
2018-03-01	0.050711	-0.018045	-0.011936	-0.083474	-0.088582	1.04875	0.987888	0.988013	0.916524	0.914686
Mean Value						**1.044610**	**1.080174**	**1.035943**	**0.983801**	**1.071474**

CHAPTER 3

Exchange Rate Return Co-movements and Volatility Spillover in BRICS countries[1]

3.1 INTRODUCTION

This essay explores into connectedness, in terms of return co-movements and volatility spillover, among BRICS foreign currency markets and currencies that are most traded globally. For this purpose, several developed country currencies including the Euro, Japanese Yen, British Pound and Australian Dollar[2] are taken into consideration. The initial chapter, while introducing the concept of volatility, has delineated that size and persistence of unanticipated shocks lead to volatility, which might spillover from one sector to other and from one country to another. The chapter is primarily concerned with volatility spillover (directional) and not contagion among currency returns.[3].

The distribution of currency returns of developed countries is similar to that of BRICS currencies presented in Chapter 1. From the summary statistics of the most traded currencies presented in Table 3.1, it can be noted that the currency return series are leptokurtic in nature, follow non-normal distribution as evident from the Jarque-Bera statistic, and are I(0)[4]. Moreover, the Ljung-Box Q statistic results show that the return series follow a random walk process except the Euro, while the Q^2 statistic suggest the presence of higher order serial correlation and non-linearity among the currency returns.

[1] A version of this chapter is revised and re-submitted to *Economic Systems* [Elsevier: ISSN 0939-3625].
[2] As observed in Appendix 1.I (Chapter 1), based on BIS Triennial Central Bank Survey (2016), these developed country currencies are most traded.
[3] Contagion is defined as the significant increase in the cross market co-movements after a shock to one country or a group of countries (Forbes & Rigobon, 2002). For literature on contagion among foreign exchange markets, see Loaiza Maya et al. (2015a, 2015b).
[4] The Phillips Perron and KPSS test statistics are presented in Table A3.1 (Appendix 3.I). The results are in conformity with the ADF test results.

The only difference in behaviour is noted in case of standard deviation of currency returns: the standard deviation of returns on Euro, Japanese Yen, British Pound and Australian Dollar are lower at 0.00609, 0.00657, 0.00608 and 0.00860 respectively than that for Brazilian Real, Russian Ruble and South African Rand. However, variations in developed country currency returns are higher than that of Indian Rupee and Chinese Yuan. These observations on volatility, serial correlation and non-linearity in BRICS and developed country currencies cannot overlook the possibility of volatility spillover among them.

Table 3.1: Summary Statistics of Developed Currency Return Series (with respect to US $)

	Euro	Japanese Yen	British Pound	Australian Dollar
Mean	-0.00001	-0.00003	0.00007	-0.00002
Std. Dev.	0.00609	0.00657	0.00608	0.00860
Variance	0.000037	0.000043	0.000037	0.000074
Skewness	-0.08466	-0.03223	1.09583	0.36436
Kurtosis	5.06663	7.65237	16.86478	13.66558
ADF Test	-55.29505 (0.000)***	-57.48998 (0.000)***	-53.59337 (0.000)***	-59.25152 (0.000)**
JarqueBera	560.73 (0.000)***	2823.35 (0.000)***	25696.70 (0.000)***	14904.75 (0.000)**
Q(30)	21.261 (0.880)	52.745 (0.006)***	50.194 (0.012)**	80.579 (0.000)***
$Q^2(30)$	1729.8 (0.000)***	847.97 (0.000)***	355.63 (0.000)***	5562.1 (0.000)***
Obs.	3130	3130	3130	3130

*Notes: ***, ** indicates significance at 1 percent and 5 percent level; p-values are in the parentheses.*
Q(1) and $Q^2(1)$ is the Ljung-Box statistic for serial correlation in return series and squared series respectively.

This chapter, in specific, investigates into the extent of return co-movement and volatility spillover in BRICS currency markets during 2006 to 2018, without splitting the entire sample period into crisis and non-crisis phases. Using Dynamic Conditional Correlation (DCC) model and Vector Autoregression (VAR) methods, the analyses show

the presence of significant return co-movements and volatility spillover between the foreign exchange markets with BRICS markets as net receivers and developed country markets as net transmitters of volatility. The study, however, estimates volatility spillover in a rolling sample framework identifying currency market volatility during turmoil and tranquil phases. The key contribution of the chapter to the existing literature lies with examining the return co-movement and volatility spillover in the foreign exchange markets of selected emerging market economies, i.e. BRICS, as against that of only developed countries.[5] The reason behind such a perception is that the pattern of volatility spillover in BRICS is likely to differ from that in developed countries.

The structure of the chapter is as follows: section 3.2 presents the review of literature, section 3.3 delineates the econometric methodology. Section 3.4 presents the empirical results. Section 3.5 concludes with summary of major findings in this chapter.

3.2 REVIEW OF LITERATURE

A large body of literature has emerged on volatility and volatility clustering in currency markets in developing economies.[6] There are some studies on volatility transmission in currency markets of both developed and developing economies. For instance, Engle et al. (1990) find supporting evidence for 'heat waves' and 'meteor showers' effects. There are instances of apparent spillover effects in the currency

[5] Sandoval (2006) deals with return co-movement in emerging markets, while (Chulia et al. (2018), Niyitegeka & Tewari (2020) study volatility spillovers between developed and emerging market economies. Return spillovers in developed countries are dealt with in a large number of studies, for instance, Ebrahim (2000); Melvin & Melvin (2003); Inagaki (2007); Kearney & Patton (2000); Hong (2001); McMillan & Speight (2010); Kitamura (2010); Antonakakis (2012) and Kocenda & Moravcova (2019), among others.

[6] See, for instance, Johnston & Scott (2000), Chong et al. (2002), Sandoval (2006), Kocenda & Valachy (2006), Narayan et al. (2009), Erdemlioglu et al. (2012) and Niyitegeka & Tewari (2020).

markets, as shown by Ebrahim (2000). Melvin & Melvin (2003), while examining volatility spillovers of the Deutsche Mark-US Dollar and Japanese Yen-US Dollar exchange rates across regional markets, find volatility in one region to be a function of own past period volatility in that region (heat wave effect) and volatility in other regions (meteor shower effect), with the former being more prominent over the latter.[7] Anderson et al. (1999) find a normality-inducing volatility transmission, high contemporaneous correlation across volatilities, pronounced and persistent temporal variation in both volatilities and correlation indicating long memory dynamics.

While Inagaki (2007), using residual cross-correlation function, finds evidence of unidirectional volatility spillover between Euro and British Pound, Hong (2001) shows bi-directional causality of spillover between two currencies. Kearney & Patton (2000) point to both direct and indirect volatility transmission within the European Monetary System. Further, some developed country currencies exhibit higher dependency during periods of joint appreciation than during periods of joint depreciation (Tamakoshi & Hamori, 2014).[8] It is further argued that markets are more likely to transmit volatility in active phases rather than in calm ones (Ghose & Kroner, 1996; Andersen & Bollerslev, 1998). Some studies, for instance Sahoo (2012), Ghosh (2014) and Lee (2010), show volatility transmission from other currencies and financial markets to developing country currency markets. Niyitegeka & Tewari (2020) show uni-directional volatility spillover from Euro to Rand during Eurozone crisis and post-crisis periods. Moreover, volatility

[7] Several others studies, including Bollerslev (1990), show that the co-movements between the currencies are significantly higher during the pre-European Monetary System than in the post European Monetary System free float period. Recent studies, including Black & McMillan (2004), Calvet et al. (2006), Perez-Rodriguez (2006), Nikkinen et al. (2006), Kitamura (2010) and McMillan & Speight (2010), find evidence of volatility spillovers and return co-movements among currency exchange rates.

[8] In contrast, Patton (2006), Chiang et al. (2007) and Boero et al. (2011) demonstrate higher correlations during periods of depreciation than in periods of appreciation.

spillover and time varying correlations increase during the crisis period indicating financial contagion among the markets. On the other hand, Gomez-Gonzalez & Rojas-Espinosa (2019) show that extreme foreign exchange market co-movements of twelve Asia-Pacific countries primarily depend on the degree of interdependence among them, but with no sign of contagion.

In addition to ascertaining existence and nature of volatility spillover, it is also important to identify currencies that are net receiver and net transmitter of volatility. Antonakakis (2012), in a DCC and VAR framework, finds that Euro is the net transmitter of volatility while British Pound is the net receiver of volatility. Moreover, the cross-market volatility spillovers are found to be bidirectional and the highest spillovers occur between European markets.[9] Kocenda & Moravcova (2019) show that conditional correlation between the new EU exchange rate and US Dollar decreases during the crisis periods and increases post-crisis. The cross-currency volatility spillover is bidirectional and is highest during global financial crises. The literature discussed above gives evidence on return co-movement and volatility spillover across currencies. These studies, however, largely concentrate on the foreign exchange markets of developed nations with little evidence on sources of volatility and volatility spillover in currency markets of emerging market economies, especially BRICS countries. An exception is perhaps Chulia et al. (2018), which investigate into volatility and quantile-based spillovers between twenty emerging and mature foreign exchange markets. The paper shows that the most liquid currencies are net-transmitters of volatility during periods of US dollar appreciation and net-receivers during periods of turbulence, while the least liquid

[9] Similar conclusions are arrived at by Chowdhury & Sarno (2004) using GARCH (1,1) method.

currencies are always net-receivers of volatility. However, in case of tail spillovers, the most liquid currencies are net-receivers of shocks, while those in the least liquid quartiles are net-transmitters. In this chapter, in sharp departure from the available evidence, the extent of return co-movement and volatility spillover in BRICS currency markets are investigated into.

3.3 THE METHODOLOGY

In the literature, there are many approaches measuring volatility in financial markets including stock and foreign exchange markets. As evident from Chapter 1, the currency returns series exhibit non-randomness, volatility clustering and ARCH effect, which is suggestive of modelling exchange rate returns volatility in a GARCH framework. In the literature, the analysis of in financial market volatility has been widely studied in ARCH-GARCH framework, *a la* Engle (1982) and further developed by Bollerslev (1986) and Nelson (1991). The ARCH-GARCH family models primarily used for modelling volatility in foreign exchange markets include, among others, FIGARCH, EGARCH, TGARCH, PARCH.[10] Several studies, for instance, Mundaca (1991), Chong et al. (2002), Mckenzie & Mitchell (2002), Narayan et al. (2009), and Erdemlioglu et al. (2012), show the superiority of GARCH family models over ARCH in understanding currency volatility.[11] The notion of correlation captures the nature of interdependence among currencies (Forbes & Rigobon, 2002), an understanding of volatility spillover helps in identifying the proliferation of shocks from one currency market to another. In

[10] Econometric enquiry in this field is carried out, among others, by Johnston & Scott (2000), Sandoval (2006), Kocenda & Valachy (2006).
[11]The detailed description of data is presented in Appendix 1.I of Chapter 1.

this chapter, in sharp contrast to Constant Conditional Correlation model, return co-movements among the foreign exchange markets are investigated using MGARCH-Dynamic Conditional Correlation (DCC) model.[12]

The DCC model, as proposed by Engle (2002)[13], explicitly captures, both conditional and unconditional, time-varying interrelations among the markets as against constant correlations. The model works in two steps. In the first step, the individual conditional variances are specified as univariate GARCH processes and, in the second step, the correlation among the series is estimated. The model has a computational advantage over other MGARCH models in that the number of parameters to be estimated in the process is independent of the number of series correlated. As a result, very large correlation matrices can be estimated. Additionally, an AR(1) term is included to correct for possible autocorrelation. The DCC model, following Engle (2002), is represented as,

$$r_t = \mu_t + \gamma_1 r_{t-1} + \epsilon_t, \quad \text{where } \epsilon_t|\Omega_{t-1} \sim N(0, H_t) \qquad \ldots\ldots(3.1)$$

$$\epsilon_t = H_t^{1/2} u_t, \quad \text{where } u_t \sim N(0, I)$$

$$H_t = D_t R_t D_t \qquad \ldots\ldots(3.2)$$

where $r_t = (r_{it} \ldots\ldots y_{nt})'$ is a n x 1 vector of exchange rate return,

$\mu_t = (\mu_{it}, \ldots, \mu_{nt})'$ is the conditional n x 1 mean vector of r_t, H_t is the conditional covariance matrix,

$D_t = diag(h_{iit}^{1/2} \ldots\ldots h_{nnt}^{1/2})'$ is a diagonal matrix of square root conditional variances, with h_{iit} being defined as any univariate GARCH type models,

[12] Perez-Rodriguez (2006), Kitamura (2010), Antonakakis (2012), Kocenda & Moravcova (2019) and Gomez-Gonzalez & Rojas-Espinosa (2019) have used such modelling strategy to decipher return co-movements in currency markets. Cappiello et al. (2006), Wang & Thi (2006), Wang & Moore (2012), Kang et al. (2016), Roy & Sinha Roy (2017) and Ngene et al. (2018) have used this method for estimating return co-movements in other financial markets.

[13] Refer to Bauwens et al. (2006) as well.

and R_t contains the time varying conditional correlations defined as

$$R_t = diag\left(q_{ii,t}^{-1/2} \dots q_{nn,t}^{-1/2}\right) Q_t diag(q_{ii,t}^{-1/2} \dots q_{nn,t}^{-1/2}) \text{ or } \rho_{ij,t} = \rho_{ji,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t} q_{jj,t}}} \quad \text{.....(3.3)}$$

where $Q_t = (q_{ij,t})$ is a n x n symmetric positive definite matrix given by

$$Q_t = (1 - \alpha - \beta)\overline{Q} + \alpha u_{t-1} u'_{t-1} + \beta Q_{t-1} \quad \text{.....(3.4)}$$

where $u_t = (u_{1t}, u_{2t}, \dots . u_{nt})'$ is the n x 1 vector of standardized residuals, $\overline{Q}$ is the (n x n) unconditional correlation matrix of u_t and α and β are non-negative scalar parameters satisfying $\alpha + \beta < 1$.

Volatility spillover among the foreign exchange markets is arrived at using the generalised vector autoregression structure (Koop et al. 1996; Pesaran & Shin, 1998), as the method leads to variance decomposition which is invariant to the ordering of the variables. The generalised VAR approach allows correlated shocks and accounts for them accurately using the historically observed distribution of the errors. Since the shocks to each variable are not orthogonalised, the sum of the contributions to the variance of the forecast error is not necessarily one. Likewise Diebold & Yilmaz (2009), in a VAR framework, find facts of contradictory performance in the dynamics of return spillovers and volatility spillovers for nineteen global equity markets.[14]

For a p-order N-variable VAR,

$$x_t = \sum_{i=1}^{p} \varphi_i x_{t-1} + \epsilon_t, \quad \text{.....(3.5)}$$

where $x_t = (x_{it}, \dots \dots, x_{nt})$ is a vector of endogenous variables, $\epsilon_t \sim (0, \Sigma)$ is a vector of independently and identically distributed disturbances. The moving average representation is $x_t = \sum_{i=0}^{\infty} A_i \epsilon_{t-1}$, where N x N coefficient matrices A_i obey the

[14] See, for instance, Diebold & Yilmaz (2012), Chulia et al. (2018) and Gomez-Gonzalez et al. (2020).

recursion $A_i = \varphi_1 A_{i-1} + \varphi_2 A_{i-2} + \ldots. + \varphi_p A_{i-p}$, with A_0 being an N x N identity matrix and with $A_i = 0$ for $i < 0$. Denoting the Koop, Pesaran & Potter (KPPS) H-step ahead forecast error variance decomposition as

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_i)} \quad \ldots\ldots.(3.6)$$

where $\sum$ is the variance matrix for the error vector ε, σ_{jj} is the standard deviation of the error term for the j^{th} equation and e_i is the selection vector with one as the i^{th} element and zeros otherwise. As mentioned above, the sum of the each row of the variance decomposition matrix is not equal to one, so each variable of the matrix is normalized by row sum, so that resultant row sum of the variables is equal to one. This is as follows,

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \quad \ldots\ldots(3.7)$$

with $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = 1$ and $\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = N$ by construction.

Using these results, the total volatility spillover index is constructed, which is as,

$$S^{g}(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} * 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} * 100 \quad \ldots\ldots(3.8)$$

This index measures the contribution of spillovers of volatility shocks across five markets to the total forecast error variance. Additionally, the directional spillovers received by market i from all other markets j are defined as

$$S_{i<}^{g}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} * 100 = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} * 100 \quad \ldots\ldots(3.9)$$

Equally the directional spillovers transmitted by market i to all other markets j are defined as

$$S_{i>}^{g}(H) = \frac{\sum_{j=1}^{N} \tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ji}^{g}(H)} * 100 = \frac{\sum_{j=1}^{N} \tilde{\theta}_{ji}^{g}(H)}{N} * 100 \quad \text{.....(3.10)}$$

and finally the net volatility spillover from market i to all other markets j is defined as

$$S_{i}^{g}(H) = S_{i>}^{g}(H) - S_{i<}^{g}(H) \quad \text{.....(3.11)}$$

The net volatility spillover shows to what extent each market, on average, contributes to the volatility of other markets and vice-versa.

In this context it is also important to examine the net pairwise volatility spillover between markets i and j, defined as the difference between the gross volatility shocks transmitted from market i to market j and vice-versa. It is different from the concept of net volatility spillover in the sense that the former is at a more disaggregated level i.e. from one market to other and not to all other markets taken together. Net-pairwise volatility spillover which, for example, reveals volatility that spills over between each pair of developed country and BRICS foreign exchange market, is represented as,

$$S_{ij}^{g}(H) = \left(\frac{\tilde{\theta}_{ji}^{g}(H)}{\sum_{i,k=1}^{N} \tilde{\theta}_{ik}^{g}(H)} - \frac{\tilde{\theta}_{ij}^{g}(H)}{\sum_{j,k=1}^{N} \tilde{\theta}_{jk}^{g}(H)} \right) * 100 = \left(\frac{\tilde{\theta}_{ji}^{g}(H) - \tilde{\theta}_{ij}^{g}(H)}{N} \right) * 10 \quad \text{.....(3.12)}$$

On the whole, Equation 3.3 estimates the Dynamic Conditional Correlation indicating return co-movements, while Equation 3.11 shows net volatility spillover between two currencies.[15] The equations will be used in this essay for the purposes of estimation.

It is important to note here that this analysis uses normal distribution for maximum likelihood estimation, although it is a standard practice to use Student's t or generalized Gaussian distribution when the ε_t follows a heavy-tailed and asymmetric distribution (Bollerslev, 1986; Bollerslev, 1987; Hsieh, 1989; and Nelson, 1991).

[15] However, a better method to measure connectedness would have been in the network framework developed by Diebold & Yilmaz (2014).

However, this technique may produce inconsistent estimator if the distribution of innovation is mis-specified. In contrast, the Gaussian Maximum Likelihood Estimation (MLE) or Gaussian Quasi Maximum Likelihood Estimation (QMLE) produces a consistent estimator (Elie & Jeantheau, 1995) and is asymptotically normal provided a finite fourth moment of the innovation exists, even if the true distribution is far from normal (Hall & Yao, 2003; Berkes et al. 2003).

3.4 THE EMPIRICAL RESULTS

In this section, the analysis is set out with estimation of time varying conditional correlation by applying Dynamic Conditional Correlation model to identify return co-movements followed by an analysis of volatility spillover among the BRICS and developed country currency markets. In this analysis, the focus is primarily on BRICS foreign exchange markets. The econometric estimation is carried out using returns[16] on exchange rate, the data on which are availed from the database described in Appendix 1.I in Chapter 1.

3.4.1 Return Co-movements

The analysis on static correlation among currency return of different countries reveals the degree of association between any two return series. Table 3.2 shows that return on Brazilian Real, Russian Ruble, Indian Rupee, Chinese Yuan and South African Rand have a significant positive correlation with returns on Euro, British Pound and Australian Dollar and negative correlation with Japanese Yen. The results indicate that returns on all BRICS currencies appreciate with an appreciation in British Pound,

[16] For the definition of exchange rate returns, please refer to footnote number 32 in Chapter 1.

Australian Dollar and Euro and vice-versa, while an appreciation in all BRICS currencies is associated with depreciation in Japanese Yen. It is important to note here that the observed positive correlation for returns on all BRICS currencies is the highest for returns on BRICS currencies with that of Australian Dollar.

Table 3.2: Unconditional Correlation of BRICS Currency Return Series

	Euro	Japanese Yen	British Pound	Australian Dollar
Brazilian Real	0.33054 (0.0000)***	-0.15781 (0.0000)***	0.33388 (0.0000)***	0.52852 (0.0000)***
Russian Ruble	0.28836 (0.0000)***	-0.04655 (0.0174)**	0.24546 (0.0000)***	0.33662 (0.0000)***
Indian Rupee	0.18593 (0.000)***	-0.08595 (0.0000)***	0.21361 (0.000)***	0.26467 (0.000)***
Chinese Yuan	0.04555 (0.0200)**	-0.00412 (0.8332)	0.05497 (0.0050)***	0.10015 (0.0000)***
South African Rand	0.42509 (0.0000)***	-0.15132 (0.0000)***	0.40466 (0.000)***	0.60969 (0.000)***

*Note: ***, ** indicates significance at 1 percent and 5 percent level; p-values are in the parentheses.*

The findings on unconditional correlation of return series presented earlier are compared and contrasted with MGARCH-DCC(1,1) results. The DCC model is estimated separately for each BRICS currency market to arrive at univariate GARCH estimates as well as to understand the co-movements of the respective currencies with that of any developed country. The estimated DCC parameters are statistically significant indicating that the second order moments of exchange rate returns is time varying. The univariate GARCH estimate of currency returns in individual BRICS and the developed economies are presented in Tables 3.3 (Panel A to E). The results throw light on how returns on BRICS currencies vary with their developed counterparts. From each panel in Table 3.3,

the variations in the individual BRICS foreign exchange market with changes in individual developed country currency market can be observed.

In case of BRICS economies, as evident from Table 3.3 (Panel A to E), the AR(1) term, (γ_1), is significant for Brazilian Real and Russian Ruble and insignificant for Indian Rupee, Chinese Yuan and South African Rand. The sum of the estimated DCC(1,1) parameters is less than unity and significant in all cases indicating that the model is well specified and there is considerable time varying co-movement among the foreign exchange markets. It is also evident from the tables that there is significant volatility persistence, as given by the sum of ARCH (α) and GARCH (β) coefficients, in the foreign exchange markets of respective BRICS countries. The exceptions to this pattern are Russian Ruble and Chinese Yuan, which are explosive in nature. The Russian Ruble is found to be explosive with only Euro and British Pound. On the whole, volatility in currency returns of individual BRICS countries and four developed economies tends to persist over a long period.

The Russian Rubble and Chinese Yuan are observed to have the tendency to move away from the mean value (Kuruvila et al. 2012; Sekhar, 2003). The observed explosive nature of the returns on Russian Ruble may be attributed to the series of events, political or financial, that occurred during the period of study. Even though the monetary authorities have intervened and changed the exchange rate regimes about five times to tackle the situation, it was not enough to control currency volatility. The State Duma elections in 2011, the Ukrainian-Russian conflict and the accession of Crimea in 2014, the large fall in global oil prices in 2014 and foreign exchange policy including the devaluation of Russian Ruble in 2016 probably contributed to the turmoil in the foreign

Table 3.3: DCC Estimation Results

Panel A: Brazilian Real and major foreign exchange markets

	Mean Equation		Variance Equation			Status of the series
	Constant(μ)	γ_1	α	β	$\alpha+\beta$	
Brazilian Real	-0.00019 (0.00012)	-0.08680*** (0.01400)	0.13230*** (0.01300)	0.85970*** (0.01290)	0.992	Volatility persists for long time
Euro	-0.00008 (0.00007)	-0.00639 (0.01240)	0.03960*** (0.00403)	0.95640*** (0.00435)	0.996	Volatility persists for long time
Japanese Yen	0.00006 (0.00010)	-0.01440 (0.01250)	0.05180*** (0.00568)	0.94220*** (0.00649)	0.994	Volatility persists for long time
British Pound	-0.00009 (0.00007)	0.02360 (0.01340)	0.05640*** (0.00631)	0.94010*** (0.00678)	0.9965	Volatility persists for long time
Australian Dollar	-0.00023*** (0.00009)	-0.02180 (0.01370)	0.06710*** (0.00649)	0.92460*** (0.00720)	0.9917	Volatility persists for long time
Multivariate DCC equation						
DCC(A)	0.03020*** (0.00216)					
DCC(B)	0.96040*** (0.00313)					

Panel B: Russian Ruble and major foreign exchange markets

	Mean Equation		Variance Equation			Status of the series
	Constant(μ)	γ_1	α	β	$\alpha+\beta$	
Russian Ruble	-0.00009 (0.00005)	0.03090** (0.01360)	0.11580*** (0.00877)	0.90150*** (0.00685)	1.0173	Explosive
Euro	-0.00008 (0.00008)	-0.02190 (0.01170)	0.05170*** (0.00431)	0.95030*** (0.00417)	1.002	Explosive
Japanese Yen	0.00008 (0.00009)	-0.00442 (0.01350)	0.05500*** (0.00747)	0.94350*** (0.00752)	0.9985	Volatility persists for long time
British Pound	-0.00008 (0.00008)	0.01440 (0.01390)	0.05910*** (0.00560)	0.94220*** (0.00572)	1.0013	Explosive
Australian Dollar	-0.00018 (0.00010)	-0.03840*** (0.01330)	0.06510*** (0.00522)	0.93330*** (0.00531)	0.9984	Volatility persists for long time
Multivariate DCC equation						
DCC(A)	0.03240*** (0.00170)					
DCC(B)	0.96750*** (0.00171)					

Panel C: Indian Rupee and major foreign exchange markets

	Mean Equation		Variance Equation			Status of the series
	Constant(μ)	γ_1	α	β	$\alpha+\beta$	
Indian Rupee	0.00001	-0.00133	0.06900***	0.92410***	0.9931	Volatility persists for long time
	(0.00007)	(0.01460)	(0.00725)	(0.00782)		
Euro	-0.00004	-0.01260	0.03780***	0.95830***	0.9961	Volatility persists for long time
	(0.00007)	(0.01130)	(0.00354)	(0.00378)		
Japanese Yen	0.00009	-0.01290	0.05110***	0.94230***	0.9934	Volatility persists for long time
	(0.00010)	(0.01430)	(0.00465)	(0.00600)		
British Pound	-0.00006	0.01200	0.05630***	0.94010***	0.9964	Volatility persists for long time
	(0.00007)	(0.01390)	(0.00657)	(0.00678)		
Australian Dollar	-0.00018	-0.04490***	0.06200***	0.92990***	0.9919	Volatility persists for long time
	(0.00010)	(0.01380)	(0.00590)	(0.00658)		
Multivariate DCC equation						
DCC(A)	0.02790***					
	(0.00204)					
DCC(B)	0.96390***					
	(0.00307)					

Panel D: Chinese Yuan and major foreign exchange markets

	Mean Equation		Variance Equation			Status of the series
	Constant(μ)	γ_1	α	β	$\alpha+\beta$	
Chinese Yuan	-0.00008***	-0.00006	0.01910***	0.98320***	1.0023	Explosive
	(0.00002)	(0.01660)	(0.00124)	(0.00087)		
Euro	-0.00007	-0.00990	0.03780***	0.95840***	0.9962	Volatility persists for long time
	(0.00008)	(0.01280)	(0.00369)	(0.00388)		
Japanese Yen	0.00007	-0.01650	0.05030***	0.94350***	0.9938	Volatility persists for long time
	(0.00010)	(0.01350)	(0.00706)	(0.00782)		
British Pound	-0.00008	0.01850	0.05370***	0.94350***	0.9972	Volatility persists for long time
	(0.00007)	(0.01250)	(0.00609)	(0.00644)		
Australian Dollar	-0.00018	-0.01850	0.06050***	0.93230***	`0.9928	Volatility persists for long time
	(0.00010)	(0.01340)	(0.00599)	(0.00654)		
Multivariate DCC equation						
DCC(A)	0.02760***					
	(0.00197)					
DCC(B)	0.96550***					
	(0.00271)					

Panel E: South African Rand and major foreign exchange markets

	Mean Equation		Variance Equation			Status of the series
	Constant(μ)	γ_1	α	β	$\alpha+\beta$	
South African Rand	0.00005 (0.00014)	-0.01020 (0.01430)	0.06830*** (0.00832)	0.92610*** (0.00937)	0.9944	Volatility persists for long time
Euro	-0.00006 (0.00007)	0.00064 (0.01280)	0.03860*** (0.00387)	0.95760*** (0.00414)	0.9962	Volatility persists for long time
Japanese Yen	0.00008 (0.00010)	-0.00036 (0.01500)	0.05000*** (0.00459)	0.94300*** (0.00536)	0.993	Volatility persists for long time
British Pound	-0.00007 (0.00007)	0.02720** (0.01290)	0.05510*** (0.00597)	0.94190*** (0.00647)	0.997	Volatility persists for long time
Australian Dollar	-0.00018** (0.00008)	-0.01340 (0.01240)	0.06200*** (0.00603)	0.93040*** (0.00675)	0.9924	Volatility persists for long time
Multivariate DCC equation						
DCC(A)	0.02930*** (0.00213)					
DCC(B)	0.96240*** (0.00311)					

*Note: ***, ** denotes significance at 1 percent level and 5 percent level. Standard errors are in the parentheses.*

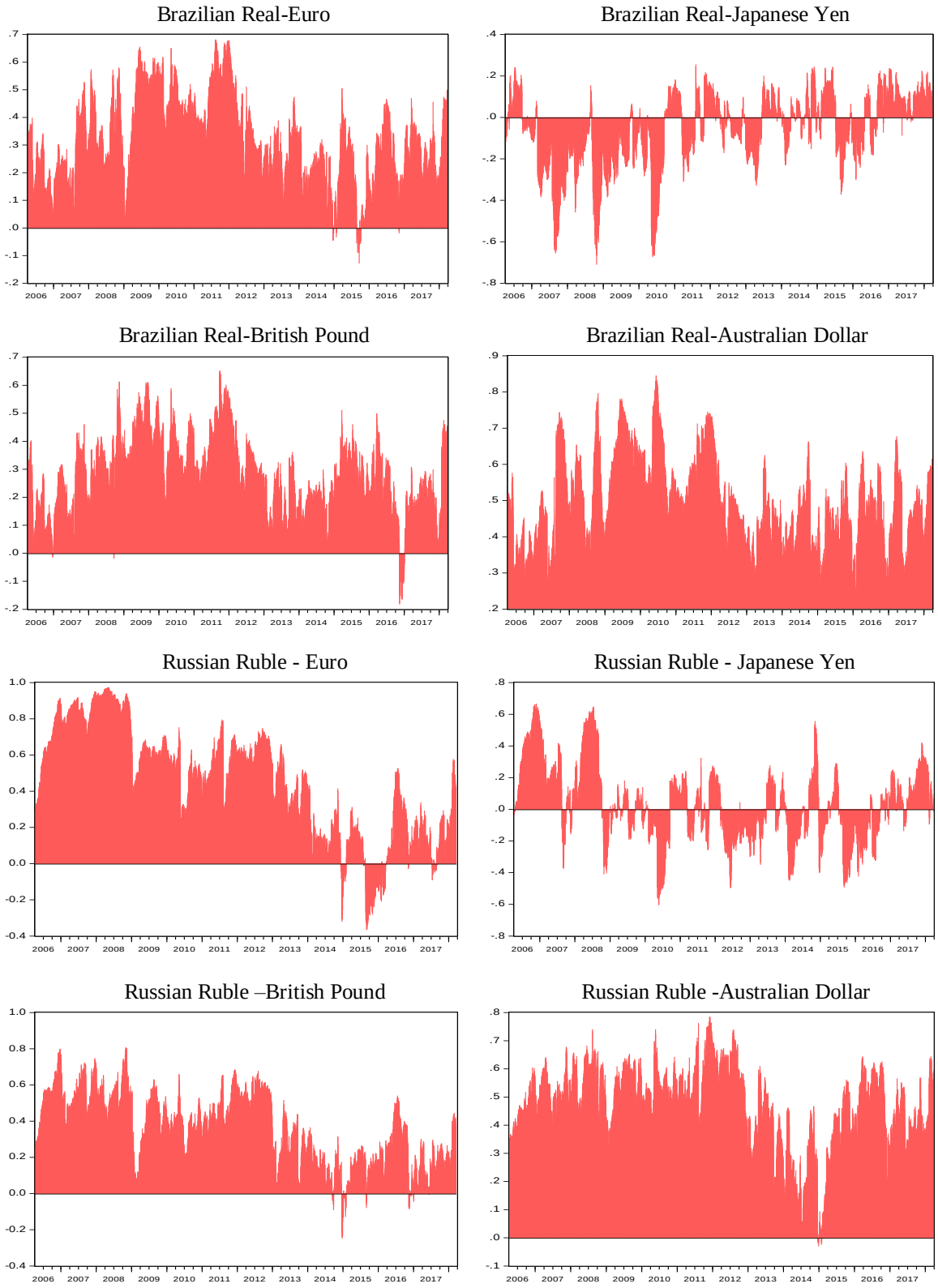
exchange market. Moreover the policy of the central bank of Russia to continuously increase the flexibility of exchange rate and gradually move towards fully floating regime has also added to the explosive nature of the Russian Ruble. On the other hand, the explosive nature of Chinese Yuan may be on account of the change in exchange rate regime from pre-announced crawling peg; *de-facto* moving band narrower than or equal to +/-1% to *de-facto* crawling peg. The global financial crisis in 2008, the Eurozone debt crisis in 2011 and the US federal Government shutdown in 2013 did not have a significant effect on the volatility of Chinese Yuan as the monetary authority have intervened to minimise the adverse effect of these events on the Chinese foreign exchange market. However, the change in exchange rate regime to *de-facto* crawling peg in December 2014 and thereafter, the occurrence of Brexit referendum in 2016, the European general election in first half of 2017 and the emergence of US-China trade war

in 2018 affected the volatility of Yuan by inducing the Chinese Yuan to move away from the mean value. In addition, the depreciation of Yuan in 2015 followed by huge capital outflows, purchasing of foreign assets by domestic residents and reduction of foreign exchange reserves due to intervention caused the exchange rate to blow up.

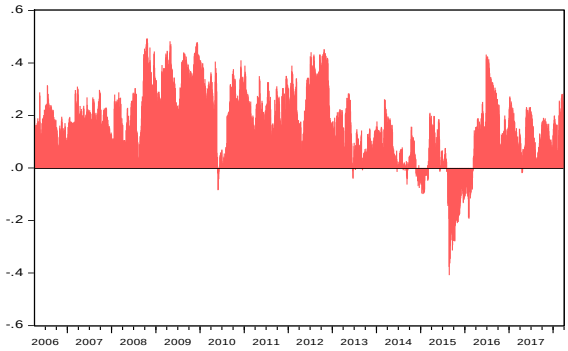
The conditional variance graphs in Figure A3.1 (Appendix 3.II) also strengthen the above argument. The graphs show the presence and persistence of volatility in the foreign exchange markets of BRICS countries with incidence of higher variance during the global financial crisis in 2008 with China being an exception. For the Indian Rupee, the conditional variance was high during 2012 as well. The degree of conditional variance for Chinese Yuan, on the other hand, is lower than that of other BRICS currencies. Evidence also point to sporadic increase in variance for returns on Brazilian Real, Russian Ruble and South African Rand during this period.

Besides, the conditional correlation graphs (Figure 3.1) reveal evidence of significant dynamic conditional correlation between individual BRICS and developed country currency markets. It shows that there is high positive correlation between Brazilian Real, Russian Ruble, Indian Rupee and South African Rand with Australian Dollar, Euro and British Pound, but the correlation, though positive, is smaller in case of Chinese Yuan. The conditional correlation for all BRICS currencies with Japanese Yen is of insignificance. It is notable from the graphs that the correlation is positive and high for all currencies for the entire sample period, the pattern is similar to conditional variance of currency returns during the sample period (as observed in Appendix 3.II).

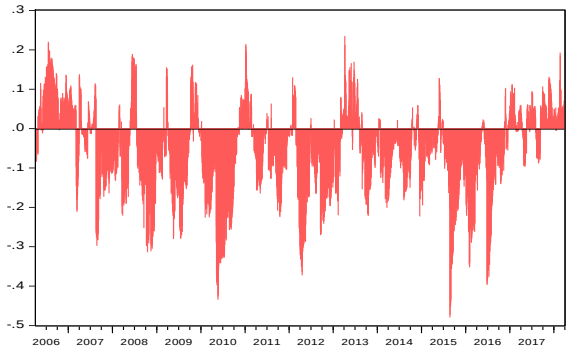
Figure 3.1: Conditional Correlation for BRICS Currencies with Developed Country Currencies



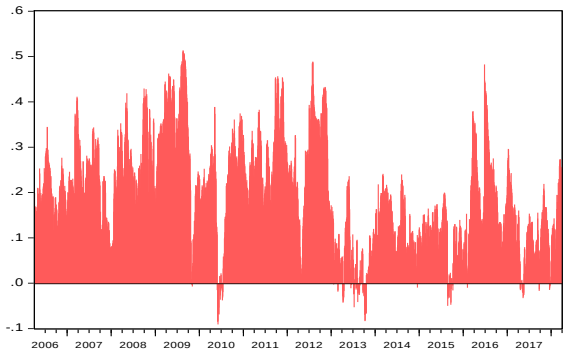
Indian Rupee-Euro



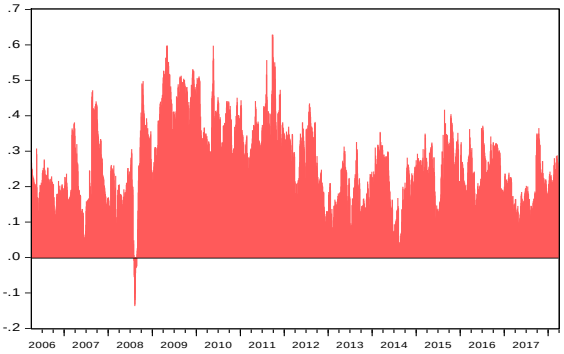
Indian Rupee -Japanese Yen



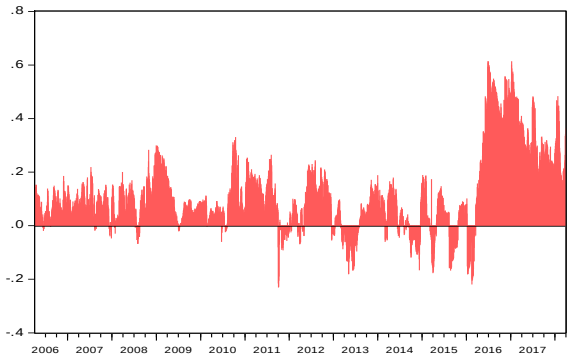
Indian Rupee -British Pound



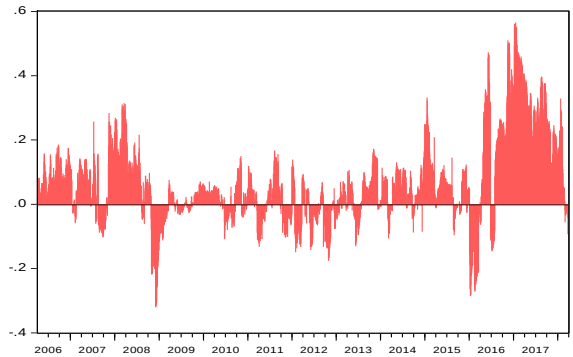
Indian Rupee -Australian Dollar



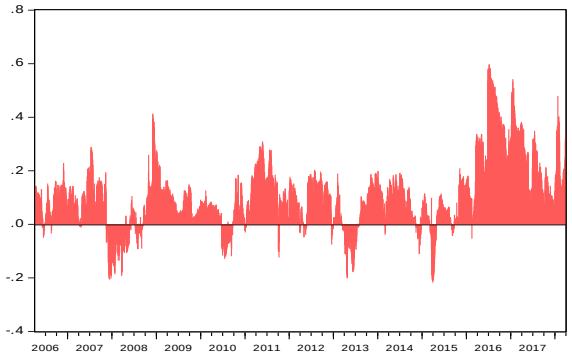
Chinese Yuan-Euro



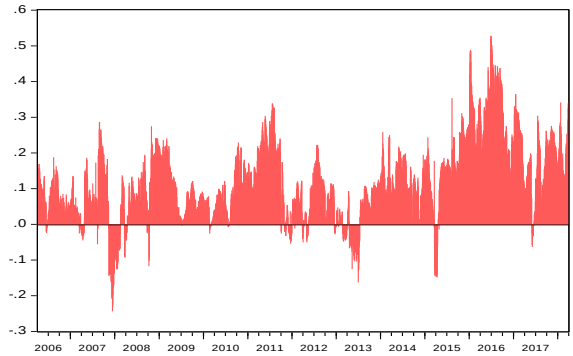
Chinese Yuan-Japanese Yen



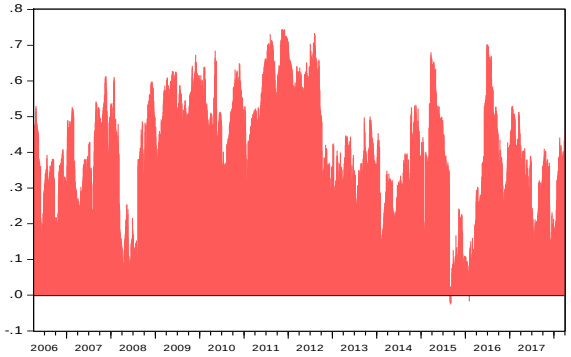
Chinese Yuan-British Pound



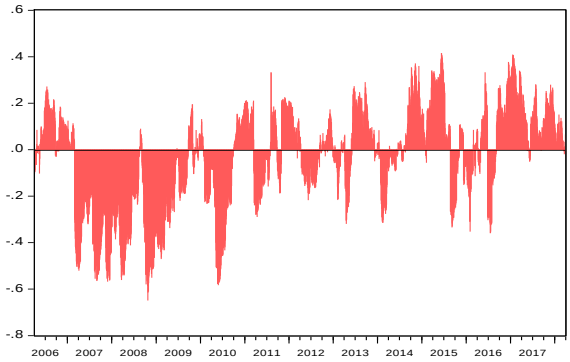
Chinese Yuan-Australian Dollar



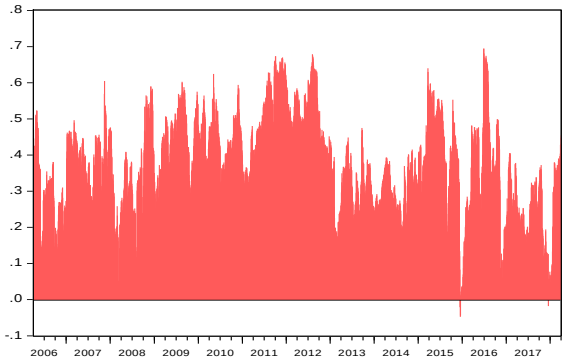
South African Rand-Euro



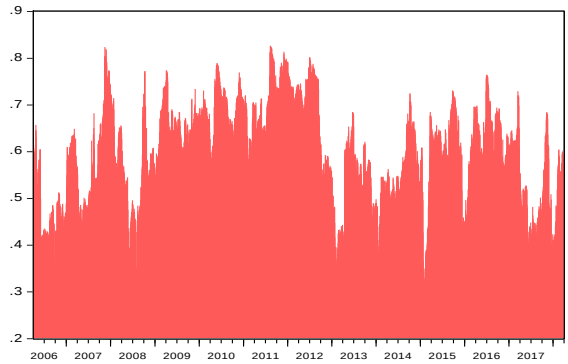
South African Rand-Japanese Yen



South African Rand-British Pound



South African Rand-Australian Dollar



The observed increases in conditional variances and correlations are possibly indicative of extreme episodes such as large capital outflows from emerging markets, including the BRICS, following the signal from FED to increase the Fed Funds rate in 2006, the global financial crisis starting in 2007-2008, the Eurozone debt crisis in 2011, the Russian financial crisis in 2014, the deep plunge in oil price during mid-2014 to 2016, the Brexit in 2016, the US elections in 2016, European general election in 2017 or the emergence of US-China trade war in 2018.

On the whole, the BRICS currencies are found to co-move with Euro, British Pound and Australian Dollar. It can be argued that the volatility of Euro, British Pound and Australian Dollar have had a significant impact on the volatility of BRICS currency

returns. The following section provides with a discussion on volatility spillover across currencies.

3.4.2 Volatility Spillover

In this section, volatility spillover between BRICS foreign currency markets and that of developed countries is estimated using VAR model as specified in Equation 3.11. In specific, the variance decomposition technique is used to measure volatility spillover. The results of the degree and direction of volatility spillover within and across BRICS economies are shown in Table 3.4 (Panel A to E).[17] Before presenting the results, it is essential to explain the rows and columns of the spillover table. The diagonal elements measure the own-market volatility spillover and the off-diagonal elements measure the cross-market volatility spillover. The off-diagonal column sum and row sum respectively are the 'to' (contributions to others) and 'from' (contribution from others) volatility spillovers in each market and the difference between 'to and from' gives the net volatility spillover from one market to other. The total volatility spillover index expressed in percentage show the grand sum of off-diagonal column (row) relative to the grand sum of column (row) including diagonals.

Some interesting results appear. In all the cases, the own market volatility spillover is found to be the highest. In case of Brazilian Real, South African Rand and Indian Rupee, the highest volatility spillover is from the Australian Dollar. In case of Russian Ruble and Chinese Yuan, the highest volatility spillover is from the Euro and the British Pound. Further, it can be observed that Brazilian Real, Indian Rupee and South African Rand pass on maximum volatility to Australian Dollar, whereas Russian Ruble

[17] It is important to note here that the cross market volatility spillover among the foreign exchange markets of BRICS countries is not significant.

and Chinese Yuan pass on maximum volatility to Euro and British Pound respectively. There is thus no unique developed market currency which plays a predominant role in volatility transmission to the BRICS currency markets. The volatility transmission from BRICS currency markets also vary with their developed counterparts. This dynamics of volatility transmission also find support from the unconditional positive correlation between BRICS currencies with Euro, British Pound and Australian Dollar.

From the 'contribution to others' row and 'contribution from others' column in the Table 3.4 below, it is evident that the BRICS currency markets show a similar pattern, the exceptions being Brazil and Russia. The foreign exchange markets of India, China and South Africa contribute lesser to and absorb more volatility from the developed markets, while it is just the reverse for Brazilian and Russian currency markets. Further, the Indian, Chinese and South African currencies are found to be net receivers of volatility, while the developed market currencies are net transmitters of volatility.[18] The highest receiver of volatility is South African Rand followed by Indian Rupee and Chinese Yuan. The Brazilian and Russian foreign exchange markets, on the other hand, are net transmitters of volatility and the developed countries are the net receivers. Furthermore, the forecast error variance (FEV) is found to be higher in cases of Brazilian Real and South African Rand than that of other BRICS currencies.

[18] Net transmitter or receiver indicates whether the contribution of volatility of a particular currency to all other currencies is greater or less than the transmission of volatility from other currencies to that particular currency. This result is primarily derived from the directional volatility spillover analysis (see Yarovaya et al., 2016;, Tereza, 2018 and Balcilar et al., 2018).

Table 3.4: Volatility Spillover Index

Panel A: Brazilian Real and major foreign exchange markets

	From					
To	Brazilian Real	Euro	Japanese Yen	British Pound	Australian Dollar	Contribution From Others
Brazilian Real	78.366	3.429	4.230	1.082	12.892	21.634
Euro	4.347	69.632	7.113	8.803	10.104	30.368
Japanese Yen	3.033	6.643	72.878	6.395	11.051	27.122
British Pound	2.064	10.989	9.067	71.288	6.592	28.712
Australian Dollar	13.382	6.951	8.077	3.398	68.192	31.808
Contribution to Others	22.826	28.012	28.488	19.679	40.640	139.644
Contribution including own	101.192	97.644	101.366	90.967	108.832	
Net Spillover	1.192	-2.356	1.366	-9.033	8.832	Spillover Index 27.929%

Panel B: Russian Ruble and major foreign exchange markets

	From					
To	Russian Ruble	Euro	Japanese Yen	British Pound	Australian Dollar	Contribution From Others
Russian Ruble	92.077	3.739	1.627	0.722	1.835	7.923
Euro	3.792	70.054	6.867	8.874	10.412	29.946
Japanese Yen	2.260	6.531	73.677	6.395	11.136	26.323
British Pound	1.405	10.663	9.006	71.977	6.949	28.023
Australian Dollar	1.304	7.557	8.856	3.828	78.454	21.546
Contribution to Others	8.761	28.490	26.356	19.820	30.332	113.760
Contribution including own	100.838	98.545	100.033	91.798	108.787	
Net Spillover	0.838	-1.456	0.033	-8.203	8.786	Spillover Index 22.752%

Panel C: Indian Rupee and major foreign exchange markets

	From					
To	Indian Rupee	Euro	Japanese Yen	British Pound	Australian Dollar	Contribution From Others
Indian Rupee	93.551	1.586	2.340	0.172	2.351	6.449
Euro	0.195	72.404	7.317	9.074	11.010	27.596
Japanese Yen	0.765	6.916	74.432	6.366	11.521	25.568
British Pound	0.369	11.138	9.128	72.340	7.025	27.660
Australian Dollar	1.322	7.588	8.698	3.788	78.604	21.396
Contribution to Others	2.651	27.228	27.483	19.401	31.907	108.670
Contribution including own	96.201	99.632	101.914	91.741	110.511	
Net Spillover	-3.798	-0.368	1.915	-8.259	10.511	Spillover Index 21.734%

Panel D: Chinese Yuan and major foreign exchange markets

To	From					
	Chinese Yuan	Euro	Japanese Yen	British Pound	Australian Dollar	Contribution From Others
Chinese Yuan	98.365	0.540	0.235	0.573	0.288	1.635
Euro	0.115	72.597	7.378	9.037	10.874	27.403
Japanese Yen	0.230	6.824	75.151	6.444	11.351	24.849
British Pound	0.536	11.054	9.269	72.083	7.058	27.917
Australian Dollar	0.150	7.548	8.784	3.790	79.729	20.271
Contribution to Others	1.031	25.966	25.666	19.844	29.571	102.077
Contribution including own	99.396	98.562	100.816	91.926	109.299	
Net Spillover	-0.604	-1.437	0.817	-8.073	9.3	Spillover Index 20.415%

Panel E: South African Rand and major foreign exchange markets

To	From					
	South African Rand	Euro	Japanese Yen	British Pound	Australian Dollar	Contribution From Others
South African Rand	75.049	2.107	3.125	4.237	15.482	24.951
Euro	2.492	70.699	7.175	8.997	10.637	29.301
Japanese Yen	3.691	6.585	72.518	6.374	10.832	27.482
British Pound	4.694	10.870	8.881	69.286	6.268	30.714
Australian Dollar	7.997	6.901	7.961	3.634	73.507	26.493
Contribution to Others	18.875	26.463	27.142	23.241	43.218	138.940
Contribution including own	93.925	97.161	99.660	92.528	116.726	
Net Spillover	-6.076	-2.838	-0.34	-7.473	16.725	Spillover Index 27.788%

Notes: Values reported are the variance decomposition based on 10-step ahead forecasts. The VAR lag length of order 1 was selected by the Hannan-Quinn Criterion.

Table 3.4 (Panel A) shows that volatility of Brazilian Real explains more than 22 per cent of FEV of other currencies as a whole, whereas 21.634 per cent of the Brazilian Real volatility is captured by other currencies in the VAR. In particular, Brazilian Real contributes about 12.90 per cent to FEV of Australian Dollar, which is the highest contribution in comparison to that of Euro, Japanese Yen and British Pound. On the other hand, the Australian Dollar also accounts for 13.382 per cent of the FEV of Brazilian Real, the highest spillover to the Brazilian currency with respect to other developed currencies. Similarly, Table 3.4 (Panel E) shows that South African Rand explains the

highest forecast error variance of Australian Dollar, and Australian Dollar accounts for the highest spillover to the South African Rand. Besides, it is also evident from Table 3.4 (Panel E), the volatility of South African Rand explains 18.875 per cent of the FEV of the other currencies, while 24.951 per cent of the South African Rand volatility is captured by other currencies in the VAR.

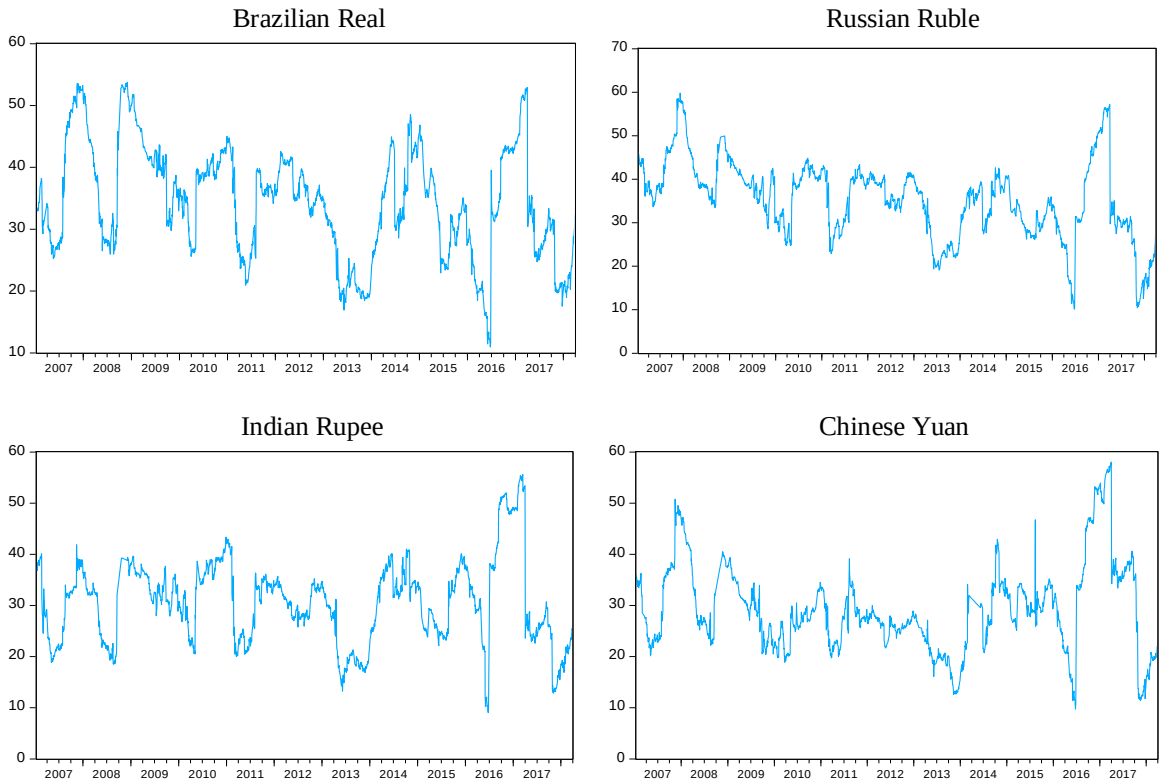
Table 3.4 (Panel B) shows that the Russian Ruble is contributes 3.792 per cent to FEV of Euro, which is higher than that of Japanese Yen, British Pound and Australian Dollar. In contrast, Euro accounts for 3.739 per cent of the FEV of Russian Ruble, the highest spillover to the Russian currency among developed country currencies. Furthermore, the volatility of Russian Ruble explains 8.761 per cent of FEV of the other currencies as a whole, whereas the other currencies explain 7.923 per cent of FEV of the Russian Ruble in the VAR. In Table 3.4 (Panel C), it is observed that the Indian Rupee explains 1.322 per cent, the highest, of the FEV of Australian Dollar. Alternatively, Australian Dollar also accounts for 2.351 per cent of FEV of Indian Rupee, the highest spillover to the Indian currency with respect to other developed currencies. It is thus noticed that the volatility of Indian Rupee explains 2.651 per cent of FEV of the other currencies, while 6.449 per cent of the Indian Rupee volatility is captured by other currencies in the VAR. Table 3.4 (Panel D) reveals that Chinese Yuan contributes the highest to FEV of British Pound. Similarly, the highest contribution to FEV of Chinese Yuan is by British Pound. Furthermore, from the table, it is clear that the volatility of Chinese Yuan explains 1.031 per cent of FEV of other currencies, whereas 1.635 per cent of the Chinese Yuan volatility is captured by other currencies in the VAR.

From the above discussion of results, it can be observed that Brazilian Real and Russian Ruble are observed to be net transmitters of volatility to the developed country currencies, which are the net receivers. In contrast, it is evident that Indian Rupee, Chinese Yuan, South African Rand are net receivers of volatility from the developed country currencies. Further, it is also revealed from the tables that the spillover index is highest for Brazilian Real (27.929 per cent) followed by South African Rand (27.788 per cent), Russian Ruble (22.752 per cent), Indian Rupee (21.734 per cent) and Chinese Yuan (20.415 per cent). This result corroborates with the earlier observation that the variance of South African Rand and Brazilian Real is higher among BRICS countries. An examination of the full table shows that the gross directional volatility spillover 'to others' is highest for Australian Dollar, while it is the highest for British Pound in case of 'from others', except for the index of Brazilian Real with major foreign exchange markets where Australian Dollar is the highest receiver of gross directional volatility spillover 'from others'. Thus, Australian Dollar is the dominant currency in transmission of volatility to other markets, while British Pound is a net receiver of volatility from other countries, with the only exception of Brazilian Real.

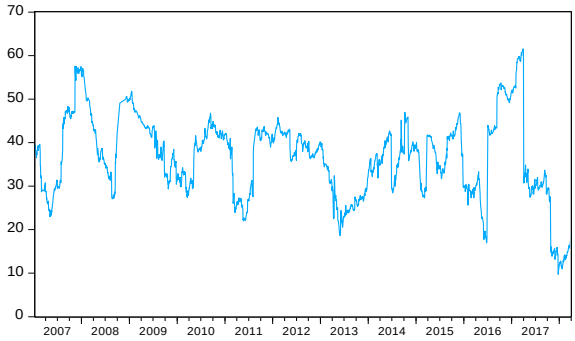
Although the spillover tables provide a summary of the behaviour of the foreign exchange markets in the BRICS countries, it does not necessarily capture the impact of several global crises that might have cropped up during the period of analysis. To deal with it, volatility spillover is estimated using 200-day rolling sample to arrive at the enormity and character of the spillovers. The total volatility spillover plots for the BRICS foreign exchange markets, as evident from Figure 3.2, are necessarily reactions to economic shocks including, among others, debt crisis, stock market crash and currency

crisis. For all the BRICS currencies, total volatility peaked during mid-2007, 2008, 2010, 2012, 2014, 2016 and 2017. This can be on account of the aftermath of dollar crisis in 2005, the capital outflow from emerging market economies in 2006, the global financial crisis in 2008, the Eurozone debt crisis in 2011, the large decline in oil prices in 2014, the Brexit referendum in 2016, the US election in 2016 or the European general elections in early 2017. However, such volatility spillover indexes do not necessarily show the directional spillover.

Figure 3.2: Total Volatility Spillover, 200-day Rolling Windows



South African Rand



The directional spillover plots, presented in Figure A3.2 (Appendix 3.II), are obtained by estimating the aforesaid row and column using 200-day rolling sample.[19] It presents the directional volatility spillover 'from others' and 'to others' for the BRICS foreign exchange markets. According to the figure, the directional spillovers 'from and to' is stronger for Brazilian Real followed by South African Rand, Russian Ruble as compared to Indian Rupee and Chinese Yuan. The directional spillover, as observed in the graphs, varies significantly overtime and is expected to respond to economic events.

Finally, Figures 3.3 and 3.4, in terms of net volatility spillover and net pair-wise volatility spillover of the BRICS foreign exchange markets, support the earlier evidence that BRICS economies being net receivers of volatility except the Brazilian Real and Russian Ruble. Among the BRICS markets, South African Rand is the highest receiver of volatility, as is evident from the magnitude of spillover from developed economies. It is followed by Indian Rupee and Chinese Yuan.

[19] Changing the rolling window to a shorter or longer window width may lead to smoothing or mounting of the graph, but the pattern of the graph and the outcome from it remains unchanged.

Figure 3.3: Net Volatility Spillover, 200-day Rolling Windows

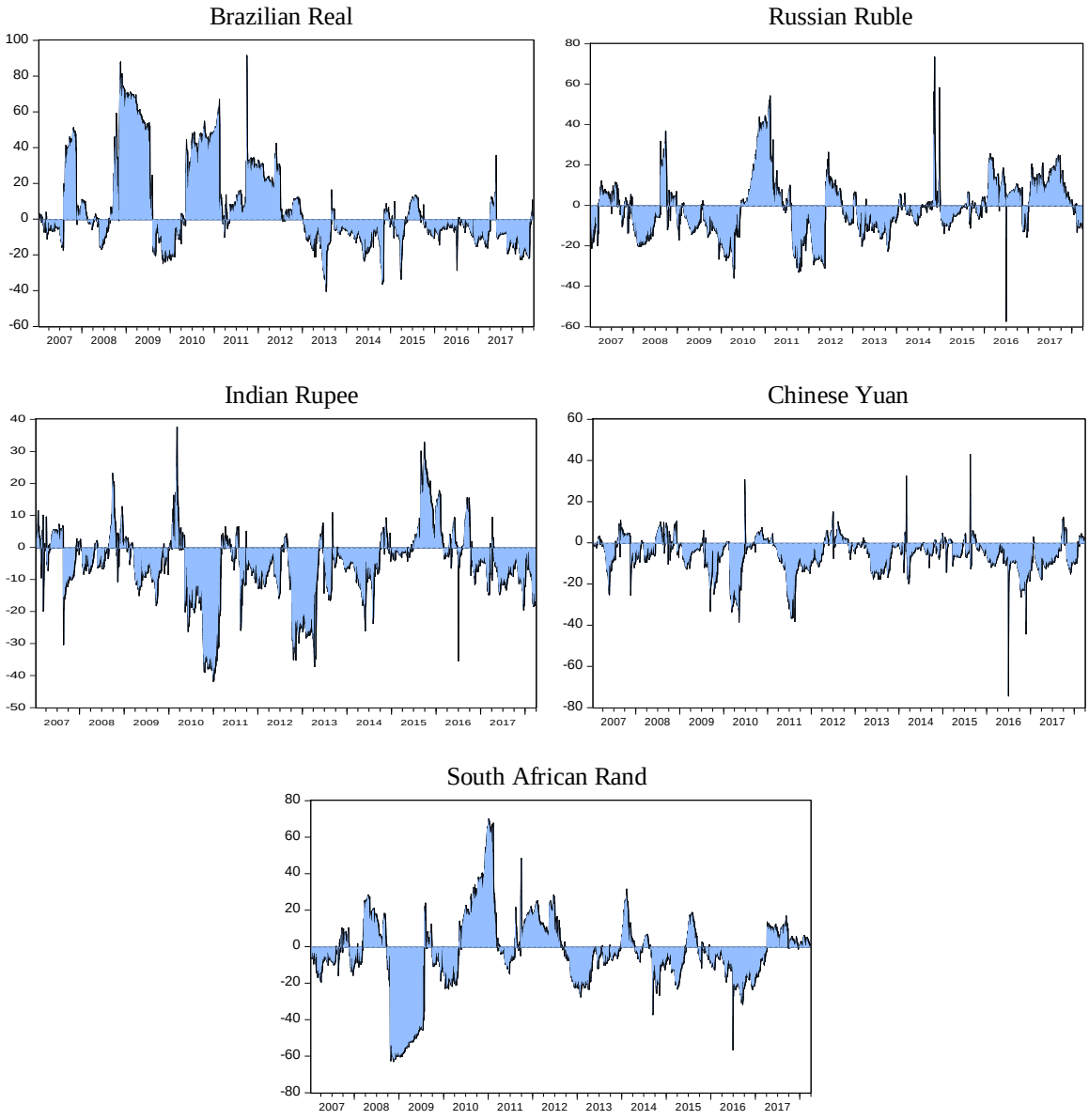
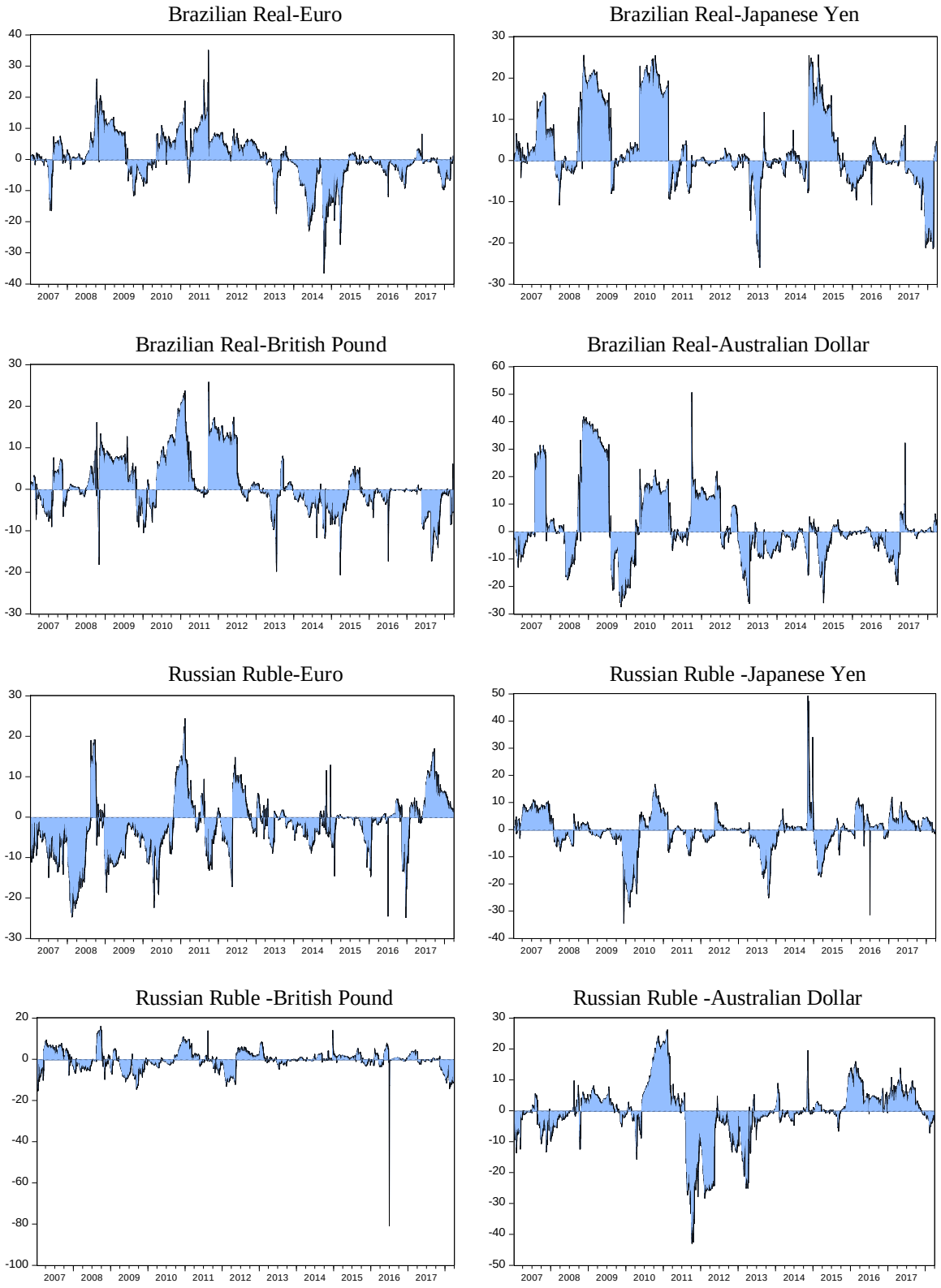
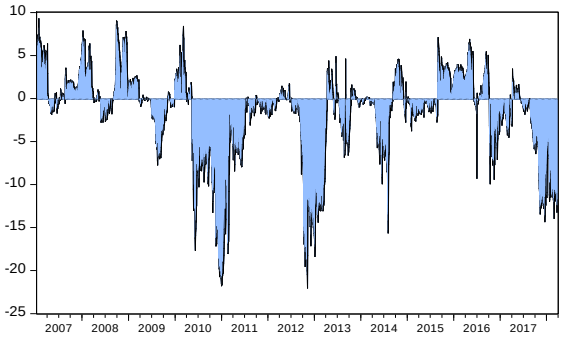


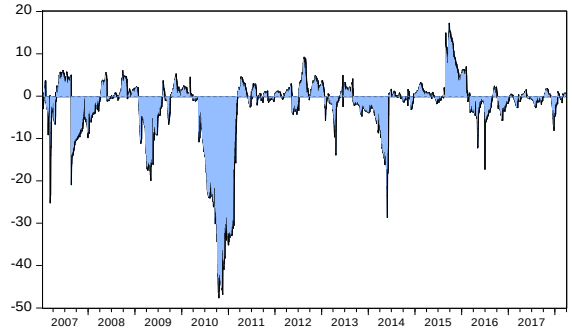
Figure 3.4: Net-Pairwise Volatility Spillover, 200-day Rolling Windows



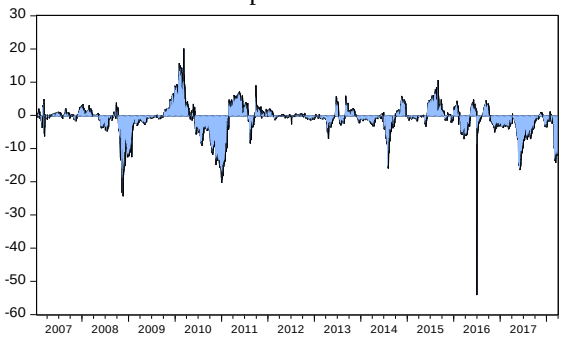
India Rupee-Euro



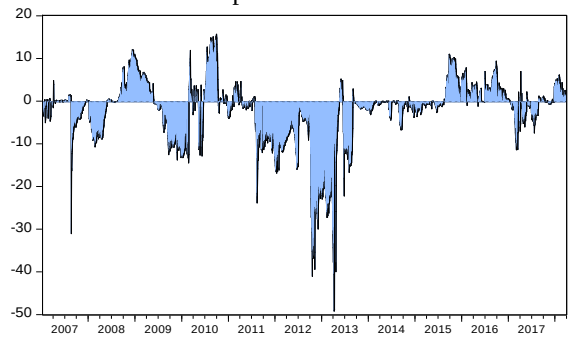
India Rupee-Japanese Yen



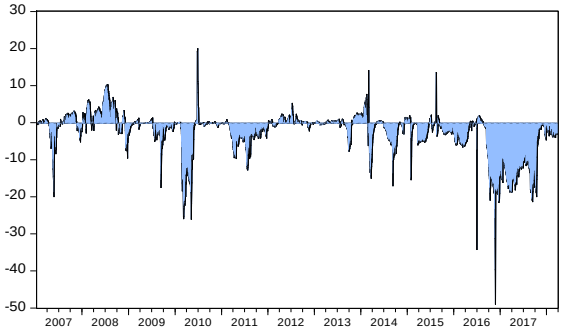
India Rupee-British Pound



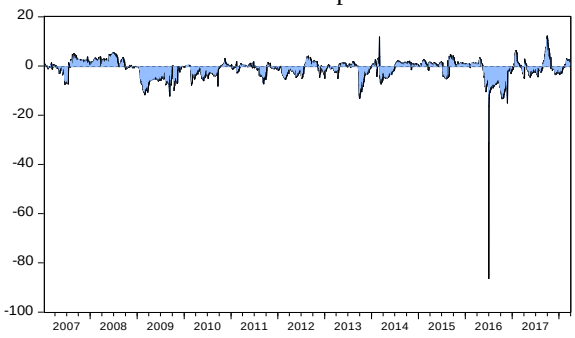
India Rupee-Australian Dollar



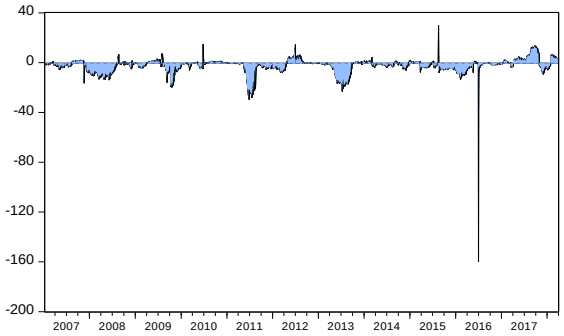
Chinese Yuan-Euro



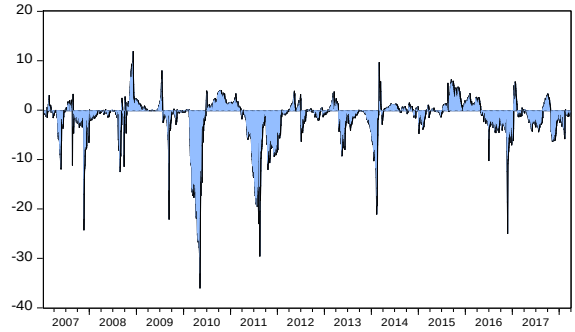
Chinese Yuan-Japanese Yen

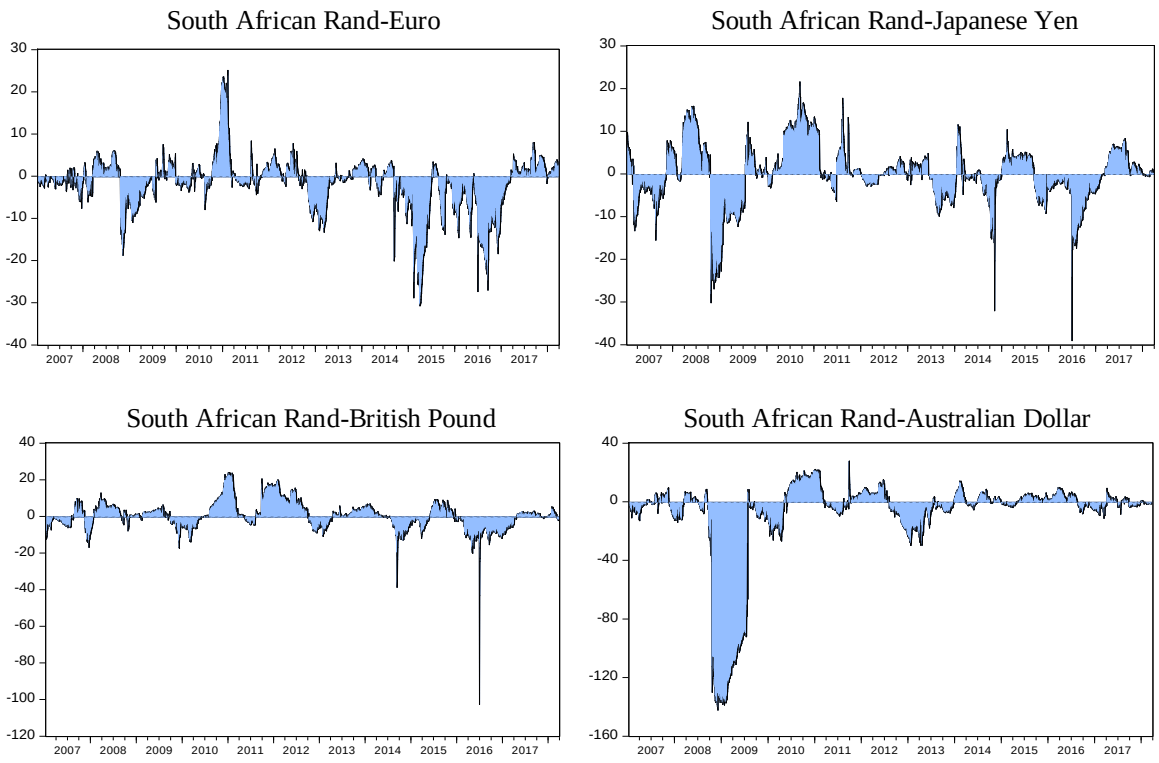


Chinese Yuan-British Pound



Chinese Yuan-Australian Dollar





On the whole, there is significant volatility spillover from developed country currencies to BRICS foreign exchange markets indicating that the latter following the former. Most of these emerging country currency markets are net receivers of volatility, with the degree of spillover varying across currencies. Further, such spillovers show large variations over time, which are necessarily synchronous with global economic trajectory. The observed linkage of individual BRICS currencies to developed country ones are perhaps on account of greater trade and foreign investment linkages between these pairs of countries, exchange rate policies/regimes, large foreign exchange reserves, interventions by the central bank as well as importance of individual foreign currencies in portfolio holding by residents/investors and the respective central bank in these emerging market economies. In addition, the extent of volatility transmission perhaps depends on

economic or political crisis that originated in these countries and interaction of individual BRICS currency markets with those of developed countries.

3.5 SUMMARY OF FINDINGS

This essay has investigated into return co-movements and volatility spillover among the BRICS and four major currencies including the Euro, Japanese Yen, British Pound and Australian Dollar during 2006-2018. Ever since currencies across countries have become market determined, the pattern of volatility has undergone a distinct change and the possibility of volatility transmission has increased. This has necessitated a detailed econometric analysis of return co-movements and volatility spillover.

The econometric analysis had set out in identifying that there is significant return co-movement among the foreign exchange markets and the volatility in the foreign exchange markets of Brazil, India and South Africa have a tendency to persist whereas the foreign exchange market of Russia and China are explosive in nature as compared to the developed economies. It can also be inferred from the analysis that Brazilian Real, South African Rand and Indian Rupee are influenced more by Australian Dollar, while Russian Ruble and Chinese Yuan are influenced more by Euro and British Pound. In addition, BRICS foreign exchange markets, except Brazil and Russia, are net receivers of volatility and developed markets are net transmitters of volatility. The investigation further reveals that South African Rand is the highest receiver of volatility among BRICS foreign exchange markets. This proposition is further supported by the statistic on spillover index and the graphs on 200-day rolling sample. Further, dynamic correlations and volatility spillovers show large variability, which are necessarily synchronous with

extreme economic episodes including global recession. The above analysis, however, does not identify such movements with major turning points and in individual BRICS economies and in the global economy. The following chapter turns to an analysis of one such factor like the economic policy uncertainty which can possibly explain volatility in BRICS foreign exchange markets.

APPENDIX 3.I

Table A3.1: Unit Root Test Statistics of BRICS and Developed Country Currencies

	Brazilian Real	Russian Ruble	Indian Rupee	Chinese Yuan	South African Rand	Euro	Japanese Yen	British Pound	Australian Dollar
PP	-59.82861 (0.000)***	-53.44785 (0.000)***	-54.18925 (0.000)***	-54.13612 (0.000)***	-56.72005 (0.000)***	-55.29474 (0.000)***	-57.53405 (0.000)***	-53.54698 (0.000)***	-59.25875 (0.000)***
KPSS (LM-Stat)	0.08386	0.10088	0.08564	0.19168	0.07352	0.08020	0.12408	0.06453	0.05586

*** *indicate significance at 1percent level.*

APPENDIX 3.II

Figure A3.1: Conditional Variance of Currency Return in BRICS

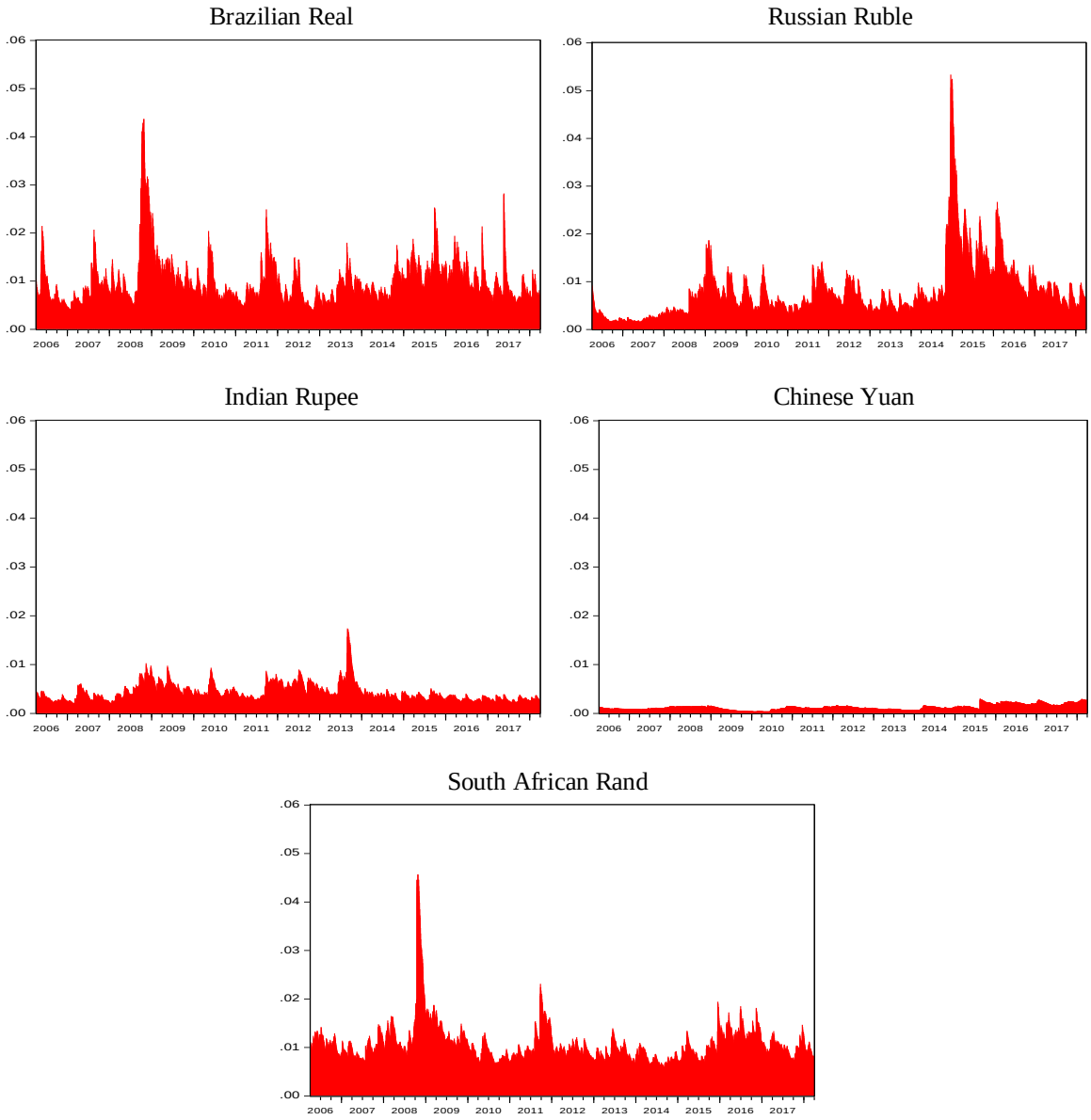
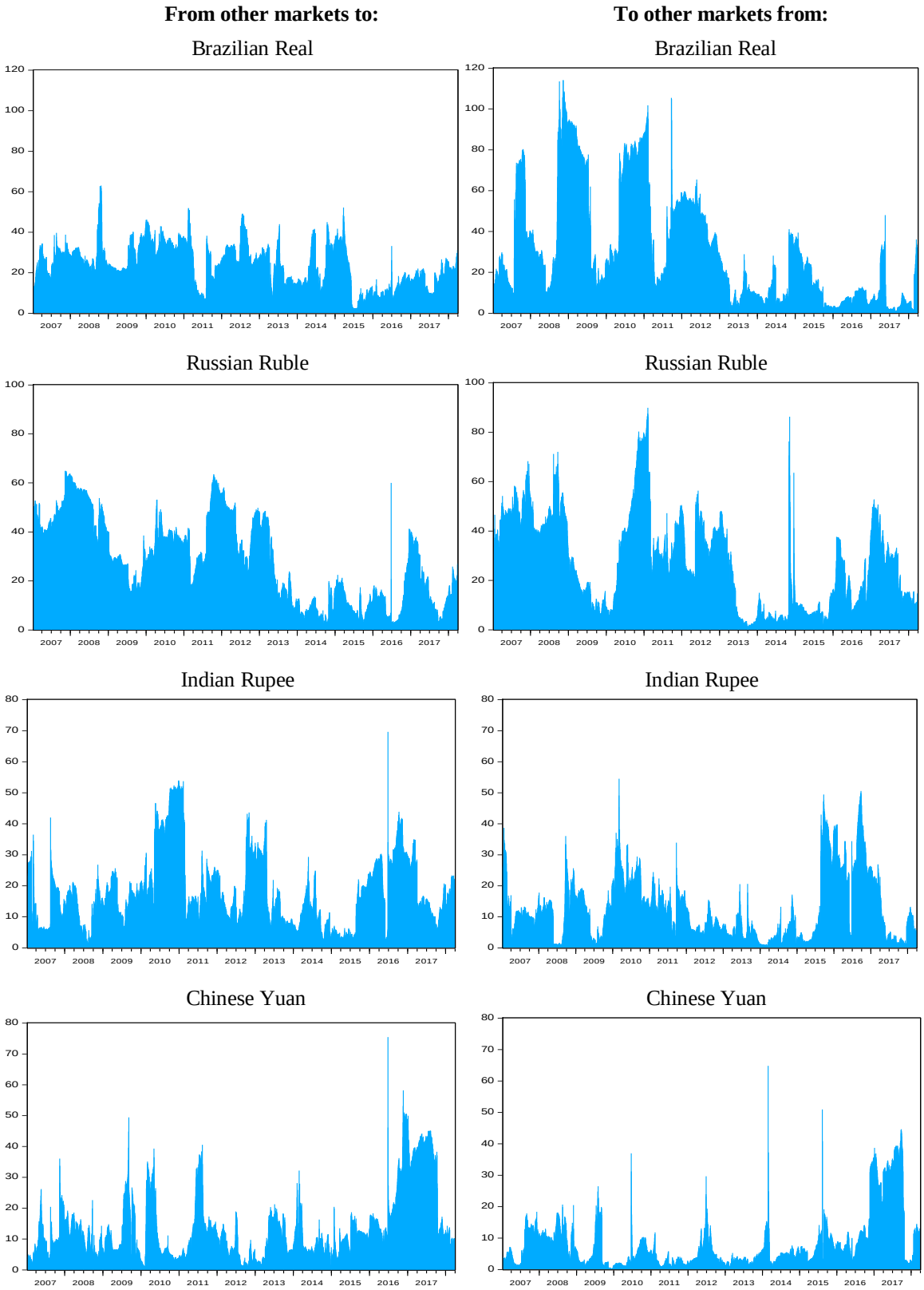
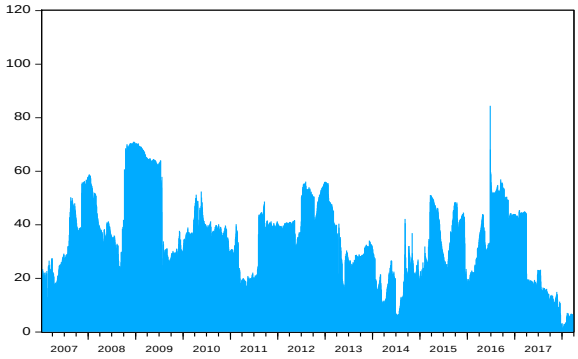


Figure A3.2: Directional Volatility Spillover



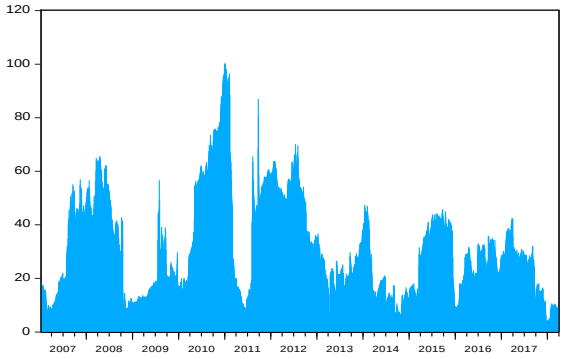
From other markets to:

South African Rand



To other markets from:

South African Rand



CHAPTER 4

Economic Policy Uncertainty and its Impact on BRICS Foreign Exchange Market Volatility

4.1 INTRODUCTION

This essay explores to identify the predictors of exchange rate volatility in BRICS countries. In earlier essays, it has been established that there are 'regime' changes in BRICS currency volatility during 2006-2018 along with return co-movements and different patterns of volatility spillover in BRICS currencies. Predicting movements in exchange rates is found to be challenging (Meese and Rogoff, 1983). Determining exchange rate volatility remains a puzzle in the literature, even though a number of studies have already attempted to examine the determinants of exchange rate volatility (see, for example, Aftab et al. 2015; Wang and Morley, 2018; Vithessonthi, 2014; among others). Different types of shocks affect exchange rate movements. Such shocks arising from political, economic and financial uncertainty often drive instability in currency markets (Al-Yahyaee et al., 2020). One such uncertainty, may be transitory in nature, is about economic policies, which induce volatility in the exchange rate market in the short run (Bartsch, 2019). The uncertainty stems from the expectations of different economic agents and, as these expectations affect both demand and supply, it is expected that a rise in economic policy uncertainty would manifest into fluctuations, wide or otherwise, in the foreign exchange market. In specific, this chapter examines the effect of economic policy uncertainty on the observed exchange rate volatility in BRICS economies.

A floating exchange rate regime is often found to induce volatility in foreign exchange markets (Betts and Devereux, 1996) and, for BRICS economies, such volatility

is high with uneven peak and trough (as evident from Figure A4.1, Appendix 4.I). The summary statistics of the exchange rate volatility and the relevant Economic Policy Uncertainty (EPU) indexes are presented in Table 4.1. The standard deviation of the EPU of Brazil, Russia, India and China are 0.579042, 0.527239, 0.506073 and 0.647238 respectively.[1] It can be observed that the dispersion in the EPU of China is the highest, while that of the US is the lowest[2]. It is interesting to note here that despite high variability in China's EPU, currency volatility is the lowest. Despite low variability in the US EPU, it is anticipated to have far reaching impact on currency volatility in the emerging market economies, in general, and the BRICS economies, in particular.

Table 4.1: Summary Statistics of BRICS Currency Volatility and EPU Indexes

Variables	Mean	Std. Dev.
$Volatility_{Brazilian\ Real}$	1.155283	
$Volatility_{Russian\ Ruble}$	0.895641	
$Volatility_{Indian\ Rupee}$	0.211291	
$Volatility_{Chinese\ Yuan}$	0.019468	
$Volatility_{South\ African\ Rand}$	1.236204	
EPU_{Brazil}	4.976058	0.579042
EPU_{Russia}	4.889862	0.527239
EPU_{India}	4.532655	0.506073
EPU_{China}	4.985616	0.647238
EPU_{US}	4.782684	0.362481

Source: BRICS currency volatility: Generalised Autoregressive Conditional Heteroskedasticity [GARCH (1,1)] model
EPU indexes: Baker et al. (2016)

The motivation behind studying the impact of EPU indexes on the currency volatility of BRICS economies follows from Figure A4.2 (Appendix 4.I). The graph

[1] It is important to mention here that the data on EPU of South Africa are not available. As a result, an analysis on the effect of own EPU on exchange rate volatility of South African Rand is not possible. However, the effect of US EPU on exchange rate volatility of South African Rand is analysed.
[2] Here the US economy is taken to represent the world economy.

presents the pattern of monthly volatility in BRICS exchange rates, calculated using a univariate Generalised Autoregressive Conditional Heteroskedasticity [GARCH (1,1)] model and the own country EPU (Local EPU) and US EPU. The left (primary) y-axis in each figure shows the range of policy uncertainties while the right (secondary) y-axis presents the volatility range. As observed earlier, the panel of figures also shows that the BRICS currencies are volatile during 2006-2018, the only exception being the Chinese Yuan. As evident from the graphs in Figure A4.2, in several instances, the BRICS currency volatility increased with the corresponding increase in domestic or/and US policy uncertainties and vice-versa. For example, volatility in most BRICS currencies amplified with the increase in uncertainty during the global financial crisis in 2008 or with the onset or aftermath of Eurozone debt crisis in 2011. The observed currency volatility in Indian Rupee, Chinese Yuan and Russian Ruble also increased to a larger extent during 2013 and 2015 on account of capital outflows from India by end 2012, adoption of a more flexible exchange rate regime in China during the latter part of 2014 or with the occurrence of the Russian financial crisis in the second half of 2014. A closer look at the graphs also reveals that the economic policy uncertainty in the US almost move in tandem with the uncertainties in the BRICS countries, which points to the fact that the volatility in BRICS currencies is primarily affected by events occurring in the domestic economy as well as in the global economy.

Based on these stylized facts, this chapter explores into whether economic policy uncertainty, within-the-country as well as global, increases exchange rate volatility of BRICS countries during 2006 to 20018. In this analysis, since exchange rates of the BRICS countries are expressed with respect to US Dollars, it is imperative to take into

the account the impact of US EPU, if any, on the BRICS foreign exchange market volatility.[3] This exercise is carried out using Heterogenous Autoregressive (HAR) model.[4] To recollect, uncertainty in economic policies is measured by Economic Policy Uncertainty index which is a news based policy uncertainty index obtained by counting the number of news articles containing a variety of country-wise uncertainty terms published therein. The analyses show that BRICS currencies are affected both by local EPU (own country EPU) and US EPU. In addition, to arrive at nuanced findings, the chapter explores the effect of regime-wise[5] EPU indexes on volatility of the BRICS currencies.

The structure of the chapter is as follows: Section 4.2 provides with a review of the existing literature on the subject and section 4.3 delineates the econometric methodology used in the study. Section 4.4 presents the empirical results on the impact of economic policy uncertainty on BRICS currency volatility. Section 4.5 summarises the major findings of the chapter.

4.2 REVIEW OF LITERATURE

A large body of literature has emerged analysing the predictors of exchange rate volatility. Apart from cross-country volatility spillovers, the literature largely revolves round the role of macroeconomic variables and expectation formation in determining exchange rate volatility. For instance, some studies have analyzed the role of different economic factors in determining foreign exchange rate volatility, while the role of

[3] It needs to be recalled that earlier essays in this thesis deal with return on BRICS currencies, which are expressed in terms of US Dollar. The analyses in those essays, regime switching as well as return co-movements and volatility spillover, thus do not take into account of the exchange rate of the US Dollar.

[4] A discussion on the method and its appropriateness is provided with in section 4.3.

[5] In this chapter, the term 'regime' refers to exchange rate policy regime instead of 'bear' and 'bull' regimes as used in Chapter 2.

commodity and other asset prices have been examined by others. Exchange rate regimes are found to be an important determinant of exchange rate volatility (Klein & Shambaugh, 2008; Bleaney & Francisco, 2010). On the other hand, studies have attempted to decipher the role of monetary policy or related variables in determining exchange rate volatility (Clare & Courtenay, 2001; Rose, 2007; Conrad & Lamla, 2010; Berganza & Borto, 2012; among others). For instance, adoption of flexible inflation targeting by the monetary policy authorities is found to reduce exchange rate volatility (Rose, 2007; Berganza & Broto, 2012). A few recent studies have also examined the role of central bank transparency on exchange rate volatility (Eichler & Littke, 2018; Weber, 2019). Further, through the import and export trade channels, economic sanctions are also found to be a determinant of exchange rate volatility (Wang et al. 2019). Even absence of an optimum currency area may lead to economic shocks to induce exchange rate volatility (Bayoumi & Eichengreen, 1998). Commodity prices or volatility in the commodity markets is also found to be a factor determining exchange rate volatility (Arezki et al. 2014).

Even though a large number of researchers have examined the predictability of exchange rate volatility using economic fundamentals as well as policies and expectations thereof, only a few have succeeded in finding the true predictors. The study by Meese & Rogoff (1983), often cited in the literature, has shown that models considering macroeconomic variables such as money supply, interest rates and output, have failed to outperform a random walk model in explaining instability in nominal exchange rate movements. Rogoff (1999) also shows that it is really challenging to

establish a relationship between exchange rate and macroeconomic variables.[6] Engel et al. (2008) argue that while modeling exchange rates one needs to consider the financial market perspective and emphasize the role of uncertainty. A number of studies in the literature argue in favour of incorporating unexpected changes in macroeconomic indicators and policies as the key predictors of exchange rate adjustment (Engle, 1982; Grier & Grier, 2006).

A rise in economic policy uncertainty leads to revisions in an economic agent's expectations of the fundamental factors that determine exchange rate, and thereby induce the exchange rate to be volatile. Using data from different expectation surveys on policy uncertainty, studies find the causal relationship between policy shocks and exchange rate volatility. Studies have established that uncertainty arising out of policy announcements or macroeconomic data is associated with higher exchange rate volatility.[7]

A number of previous studies have examined the relationship between monthly economic policy uncertainty (EPU) indices[8] and exchange rate volatility (see, for example, Krol, 2014; Balcilar et al. 2016; Kido, 2016; Bartsch, 2019).[9] Krol (2014), Balcilar et al. (2016) and Kido (2016) have used monthly EPU indices as predictors of exchange rate volatility. Krol (2014) finds mixed evidence of EPU on exchange rate volatility. For some countries, EPU of own country is found to have more effect on exchange rate volatility and, for some others, US EPU is found to have significant effect.

[6] See Frankel & Rose (1995) for a survey on studies examining the relationship between exchange rate and macroeconomic variables.

[7] See Neely (2011), for example, for a survey on empirical studies on this issue.

[8] As noted in Chapter 1, EPU index is constructed from newspaper articles by Baker et al. (2016) and Brogaard & Detzel (2015).

[9] There are studies which show the impact of EPU on macroeconomic variables. For instance, Balcilar (2020) shows asymmetric effect of US EPU on the macro variables of China, Hong Kong and South Korea during the period of quantitative easing and reverse quantitative easing, while EU EPU causes the Chinese and the South Korean economies to be more susceptible to changes during the Eurozone debt crisis.

Balcilar et al. (2016) find that EPU affects exchange rate volatility rather than exchange rate returns for most of the currencies in developed and developing countries. Bartsch (2019) finds that the UK EPU has larger effect on US-UK exchange rate volatility than the US EPU. Although Balcilar et al. (2016) find evidence that a one month lag of EPU is more effective in explaining exchange rate volatility; no such evidence is found in Bartsch (2019). Bush & Noria (2020) show that EPU in addition to domestic political uncertainty (DPU) as well as VIX (Chicago Board Options exchange volatility index) have a positive and significant effect on MXN/USD exchange rate with the effect of DPU on the exchange rate volatility increasing during recessions.

Most of the studies have examined the effects of either own country EPU or the US EPU (that is, EPU of the country with base currency) on exchange rate volatility. Some other studies have also examined the effects of major countries (or major trading partners) on the exchange rate volatility in the home country. Considering currencies from ten developed markets, Liu et al. (2019) show that changes in news implied volatility can positively and significantly affect the fluctuations in case of most currencies considered. Furthermore, their results suggest that long-term volatility is driven by variations in different types of news concerning Financial Intermediation, Natural Disasters, Stock Markets, Government, and War. Omrane & Savaser (2017), while examining the reaction of volatility to macroeconomic news in the euro, pound and yen markets during the global financial crisis, also assert that the uncertainties regarding Fed funds rates on exchange rate volatility is stronger during financial turmoil. Chen et al. (2020), however, find heterogeneous relationship between foreign currency volatility and EPU of developed countries including US, Europe, Japan, Hong Kong.

On the whole, the review of studies shows that EPU has significant effect on currency market volatility in some countries, while it is insignificant for some others. For some countries, economic policy uncertainty is found to increase exchange rate volatility, especially in the time of economic crisis. Global economic policy uncertainty also increases volatility in the absence of any intervention. These differences are on account of varying degrees of integration with the international market. However, these existing studies are largely on developed countries, and there are rarely any study linking economic policy uncertainty and BRICS currency volatility.

4.3 THE METHODOLOGY

In modelling long memory volatility, the standard GARCH or stochastic volatility models are found to be inappropriate. Long memory is usually modelled in FIGARCH framework using fractional difference operators or ARFIMA models.[10] However, the fractionally integrated models are non-trivial to estimate and lack economic interpretation. Moreover, it is also difficult to extend these models to a multivariate framework (Comte & Renault, 1998). The Heterogeneous Autoregressive Model (HAR), as proposed by Corsi (2009), is constructed following the Heterogeneous Market Hypothesis of Muller et al. (1993), which is based on the existence of heterogeneity among the traders. This model is an autoregressive model with an additive cascade of volatility components from low to high frequencies, which capture the interrelation between exchange rate volatility and EPU indexes. These volatility components are a

[10] For literature on the application of FIGARCH and ARFIMA models in modelling long memory volatility, see Baillie et al. (1996), Bollerslev & Mikkelsen (1996), Baillie & Chung (2002), Beine et al. (2002), Banerjee & Sarkar (2006), Baillie et al. (2007), Antonakakis (2007), Chin et al. (2008), Sheng & Chen (2009), Goudarzi (2010), Mukherjee et al. (2011), Sawant & Yadav (2011) and Q. Li, Tricaud, Sun, & Chen (2007).

result of the perception of different market participants at different points of time. The volatility components mainly take into account the heterogeneity in their trading pattern which arises from their difference in endowments, institutional constraints, risk profiles dissimilarity in processing information, temporal horizons and geographical locations (Corsi, 2009). Interestingly enough, even though the HAR model does not belong to the class of long memory models, it fits well into the implied volatility models and is able to capture volatility persistence observed, among other properties, in financial data. In the literature, as in Corsi (2009), this model is also found to be appropriate for forecasting.

In this essay, monthly, quarterly, half-yearly and annual time horizons are used to model volatility in BRICS foreign exchange markets. The Pure HAR model is represented as,

$$\sigma_t = \alpha_0 + \alpha_1\sigma_{t-1} + \alpha_2\frac{\sum_{m=1}^{3}\sigma_{t-m}}{3} + \alpha_3\frac{\sum_{m=1}^{6}\sigma_{t-m}}{6} + \alpha_4\frac{\sum_{m=1}^{12}\sigma_{t-m}}{12} + \varepsilon_t \quad \text{…..(4.1)}$$

where σ is the volatility at time t and ε_t denotes the error term. In addition, the effect of own country EPU (Local EPU) and the US EPU on the foreign exchange volatility of the BRICS nations are also considered. The two variants of the model are as follows:

(i) the HAR-Local EPU,

$$\sigma_t = \alpha_0 + HAR\ Components + Local_{EPU} + \varepsilon_t \quad \text{…..(4.2)}$$

(ii) the HAR-US EPU,

$$\sigma_t = \alpha_0 + HAR\ Components + US_{EPU} + \varepsilon_t \quad \text{…..(4.3)}$$

These two variants of the model help identify whether local EPU of individual BRICS countries or/and the US EPU impact on the volatility of BRICS foreign exchange markets. In the latter part of the essay, the exchange rate regimes of the BRICS nations, as classified by Ilzetzki, Reinhart and Rogoff (2016), are taken into account by

introducing regime-wise dummy into the HAR-Local EPU and HAR-US EPU model to investigate whether the impact on BRICS exchange rate volatility is regime specific. The empirical model, taking exchange rate regimes into account, is as follows,

$$\sigma_t = \alpha_0 + HAR\ Components + \sum_{D=1}^{K} D * Z + \varepsilon_t \quad \ldots\ldots(4.4)$$

where 'D' is the exchange rate regime dummy and Z represents the local EPU of BRICS countries or US EPU. The regime dummy 'D' introduced in Equation 4.4 is country-specific and, in particular, it follows the regime classification as in Table 1.1 (Chapter 1). It is important to mention here that the empirical analysis uses Implied Volatility which is obtained from AR(1)-ARCH model specification.

For evaluation of (in-sample) forecast performance of aforementioned models, three tests, namely the Campbell-Thompson test, the Diebold-Mariano test and the Clark-West test, are used. The Campbell-Thompson test (following Campbell & Thompson 2008) is computed as follows:

$$QR^2 = 1 - (MSE_u / MSE_r) \quad \ldots\ldots(4.5)$$

where MSE_u and MSE_r are the mean square are the mean square error(MSE) of the prediction from the restricted and unrestricted models, respectively. A positive QR^2 implies that the unrestricted model outperforms the restricted model and vice-versa. The second test that has been applied to compare the forecast performance of the restricted and unrestricted models is the Diebold & Mariano (2002) test. The loss difference between the two forecasts; from restricted and unrestricted models, is defined as follows:

$$d_t = g(e_{r,t}) - g(e_{u,t}) \quad \ldots..(4.6)$$

where $e_{r,t} = (\hat{\pi}_t^i - \pi_t)$; $i = r, u$ and the loss function is defined as the squared-error loss function. To test the equal forecast accuracy of the two forecasts, the null hypothesis $H_0: E(d_t) = 0$ has been tested. Under the null hypothesis, the D-M statistic is defined as:

$$D = \frac{\bar{d}}{\sqrt{\frac{1}{T}V(d)}} \sim N(0,1) \quad \text{.....(4.7)}$$

where $\bar{d} = \frac{1}{T}\sum_{t=1}^{T}[g(e_{r,t}) - g(e_{u,t})]$ is the sample mean loss function and V(d) is the unconditional variance of d. The last test is the Clark & West (2007) test which involves computing the equation,

$$f_t = (\pi - \hat{\pi}_t^r)^2 - [(\pi - \hat{\pi}_t^u)^2 - (\hat{\pi}_t^r - \hat{\pi}_t^u)^2] \quad \text{.....(4.8)}$$

where $(\pi - \hat{\pi}_t^r)^2$ and $(\pi - \hat{\pi}_t^u)^2$ are squared error from the restricted and unrestricted models, respectively. Now, to test the equality of forecast performance of restricted and unrestricted models on the basis of C-W test, f_t is regressed on a constant and the resulting t-statistics is reported.

4.4 THE EMPIRICAL RESULTS

The empirical analysis on the impact of EPU index on exchange rate volatility of BRICS countries in different time horizons are carried out in this section based on four variants of the HAR model specified as Equations 4.1, 4.2, 4.3 and 4.4 using data on BRICS exchange rate and EPU indexes, as described in Appendix 1.I. The empirical estimations showcase the effect of own country or Local EPU and US EPU on volatility of exchange rate, aggregated over four different time horizons, in BRICS economies. It is important to reiterate here that as data on Local EPU of South Africa are not available, so the effect of only US EPU on the volatility of South African Rand is looked into. The

explanatory power in terms of the adjusted R^2 is found to have improved over the variants of the model indicating that local EPU, US EPU and exchange rate regimes together provide a better explanation of BRICS currency volatility. Now, it is important to turn to a more detailed and nuanced analysis.

4.4.1 Heterogenous Autoregressive Model

Volatility of BRICS currencies is mostly affected by their own volatility components, as is evident from the estimation of Pure HAR model presented in Table 4.2. For instance, the volatility of the BRICS currencies, except the Chinese Yuan, is positively affected by own monthly volatility and negatively affected by own quarterly volatility components. Besides, the volatility of Brazilian Real and South African Rand is also positively affected by own half-yearly volatility component at 5 percent and 10 percent significance levels respectively, whereas the volatility of Chinese Yuan is only weakly associated with own yearly volatility component. These results reaffirm the results in Chapter 3.

Table 4.2: BRICS Currency Volatility: Pure HAR Estimate

$\boldsymbol{Variables}$	$\sigma_{Brazilian\ Real}$	$\sigma_{Russian\ Ruble}$	$\sigma_{Indian\ Rupee}$	$\sigma_{Chinese\ Yuan}$	$\sigma_{South\ African\ Rand}$
$\boldsymbol{Constant}$	0.4890***	0.1823*	0.0600***	0.0018	0.4254***
	(0.1580)	(0.1012)	(0.0228)	(0.0031)	(0.1025)
$\sigma_{1-month\ mean}$	0.7892***	1.0878***	0.6714***	0.0962	0.8230***
	(0.1012)	(0.2189)	(0.1637)	(0.1157)	(0.1261)
$\sigma_{3-month\ mean}$	-0.2693**	-0.5319*	-0.0288	-0.1285	-0.3565**
	(0.1200)	(0.2780)	(0.1323)	(0.1785)	(0.1483)
$\sigma_{6-month\ mean}$	0.1340**	0.1600	-0.0342	0.1518	0.1554*
	(0.0627)	(0.1637)	(0.1988)	(0.5233)	(0.0848)
$\sigma_{12-month\ mean}$	-0.0785	0.0838	0.1086	0.8385*	0.0346
	(0.0590)	(0.0892)	(0.1727)	(0.4946)	(0.0834)
$\boldsymbol{Adjusted\ R-Squared}$	0.4108	0.6580	0.4302	0.2103	0.4390

*Note: ***, ** and * indicates significance at 1 percent, 5 percent and 10 percent level. Standard errors are presented in the brackets.*

The magnitude of the yearly volatility component for the Chinese currency is higher than that for other BRIC countries. The magnitude of the coefficients of the volatility components reported in Table 4.2 gradually decreases as the time horizon increases, except the case with Chinese Yuan. The exchange rate changes with long past horizons are not found to have any effect on the current exchange rate. It is probably indicative of the fact that as the exchange rate arrangements of these countries follow a *de facto* crawling peg, free float or dirty float management system, the volatility of these currencies are more dependent on its recent past volatility rather than the volatility of longer time horizons. These results also point to the fact that ever since exchange rates became market determined or there is a tendency to move towards more flexible exchange rate regime, the current exchange rate is mainly influenced by its recent past exchange rate changes or the market microstructure (Evans & Lyons, 2002; Lyons, 1995; Yao, 1998; Covrig & Melvin, 2002; Ito, Lyons & Melvin, 1998; Cheung & Wong, 2000; Bjonnes & Rime, 1998; Evans, 1999; Naranjo & Nimalendran, 2000 and Payne, 2003).

4.4.2 Local & US Economic Policy Uncertainty

Apart from Pure HAR effects, as observed before, exchange rate volatility is also said to depend on local and US economic policy uncertainty. In addition to own volatility of various time horizons, Table 4.3 presents the results of the effect of own country EPU on the volatility of BRICS currencies. It can be observed from the table that volatility of Brazilian Real, Russian Ruble and Indian Rupee are positively affected by own monthly volatility, whereas own quarterly volatility negatively affects the volatility of Brazilian Real and Russian Ruble only. The own country EPU is only having a positive effect on the volatility of Brazilian Real and Indian Rupee at 5 percent and 10 percent significance

levels respectively. Besides, own volatility at longer horizons such as six and twelve months do not have any significant effect on the volatility of BRIC countries.

Table 4.3: Local EPU & BRICS Currency Volatility: HAR Estimate

$Variables$	$\sigma_{Brazilian\ Real}$	$\sigma_{Russian\ Ruble}$	$\sigma_{Indian\ Rupee}$	$\sigma_{Chinese\ Yuan}$
$Constant$	-1.8652* (1.0158)	-1.7258 (1.2372)	-0.3859** (0.1480)	-0.0053 (0.0076)
$\sigma_{1-month\ mean}$	0.7618*** (0.0947)	1.0569*** (0.2025)	0.6129*** (0.1461)	0.0856 (0.1277)
$\sigma_{3-month\ mean}$	-0.2469** (0.1230)	-0.5400** (0.2724)	-0.0270 (0.1291)	-0.1090 (0.1753)
$\sigma_{6-month\ mean}$	0.0481 (0.0878)	0.1947 (0.1687)	-0.0188 (0.1849)	0.1547 (0.5224)
$\sigma_{12-month\ mean}$	-0.0364 (0.0784)	0.0437 (0.1120)	-0.0165 (0.1148)	0.6886 (0.4306)
$Local_{EPU}$	0.4844** (0.2358)	0.3983 (0.2767)	0.1061*** (0.0375)	0.0019 (0.0022)
$Adjusted\ R-Squared$	0.4412	0.6685	0.4759	0.2095

*Note: ***, ** and * indicates significance at 1 percent, 5 percent and 10 percent level. Standard errors are presented in the brackets.*

Having understood the impact of local economic policy uncertainty on the volatility of individual BRICS currencies, it is important to understand the impact of global economic policy uncertainty. The US EPU is found to have a positive effect only on the volatility of Indian Rupee at 5 percent significance level (see Table 4.4). From Table 4.4, it is also evident that impact of own monthly volatility on the volatility of Brazilian Real, Russian Ruble, Indian Rupee and South African Rand is positive and significant.

On the other hand, the volatility of Brazilian Real, Russian Ruble and South African Rand are negatively affected by own quarterly volatility. Additionally, the volatility of South African Rand is also positively affected by own half-yearly volatility respectively at 10 percent. The only exception to this pattern is the volatility of Chinese

Yuan which is neither affected by its own volatility nor by own country EPU and US EPU. These results indicate that apart from own volatility, local policy uncertainty affects the exchange rate volatility of Brazilian Real and Indian Rupee, whereas US economic policy uncertainty has a significant effect only on the Indian Rupee.

Table 4.4: US EPU & BRICS Currency Volatility: HAR Estimate

$Variables$	$\sigma_{Brazilian\ Real}$	$\sigma_{Russian\ Ruble}$	$\sigma_{Indian\ Rupee}$	$\sigma_{Chinese\ Yuan}$	$\sigma_{South\ African\ Rand}$
$Constant$	-2.6666	-0.0256	-0.2592*	-0.0122	-2.2396
	(2.3225)	(1.0268)	(0.1370)	(0.0107)	(1.8813)
$\sigma_{1-month\ mean}$	0.7849***	1.0871***	0.6356***	0.0830	0.8200***
	(0.0971)	(0.2222)	(0.1702)	(0.1247)	(0.1220)
$\sigma_{3-month\ mean}$	-0.3001**	-0.5302*	-0.0144	-0.1034	-0.3927**
	(0.1300)	(0.2845)	(0.1374)	(0.1713)	(0.1568)
$\sigma_{6-month\ mean}$	0.1074	0.1609	-0.0652	0.1571	0.1479*
	(0.0790)	(0.1615)	(0.2012)	(0.5147)	(0.0789)
$\sigma_{12-month\ mean}$	-0.0466	0.0807	0.1363	0.7704	0.0366
	(0.0578)	(0.0816)	(0.1652)	(0.4731)	(0.0761)
US_{EPU}	0.6670	0.0437	0.0678**	0.0031	0.5688
	(0.5197)	(0.1997)	(0.0321)	(0.0026)	(0.4140)
$Adjusted\ R-Squared$	0.4326	0.6556	0.4377	0.2118	0.4603

*Note: ***, ** and * indicates significance at 1 percent, 5 percent and 10 percent level. Standard errors are presented in the brackets.*

The effects of own EPU and US EPU on the exchange rate volatility of the BRICS economies presented above, however, do not account for changes in exchange rate regimes in the BRICS countries during 2006-2018. It is important to note here that with the changing financial and monetary system and capital flows to and from these emerging market economies, the monetary authorities have often chosen to switch their exchange rate regimes from fixed to crawling peg to flexible as these changes have a significant effect on the exchange rate of any particular country. It is also instructive to note from Chapter 1 that the BRICS economies have adopted a number of exchange rate regimes depending on the prevailing economic conditions and, at the same time, in

response to financial sector changes occurring in the world economy. Based on this perspective, an empirical investigation strategy is adopted on the effect of own EPU and US EPU on the exchange rate volatility of the BRICS countries, given the exchange rate regime. To arrive at regime-wise effects of local and US EPUs, these variables are interacted with regime dummies.

4.4.3 Exchange Rate Regime Dummy and Economic Policy Uncertainty

In this subsection, the regime-wise effects of local and US EPU on the exchange rate volatility of BRICS economics are analysed. It is evident from Table 4.5 that volatility in some BRICS currencies (Brazilian Real, Russian Ruble and Indian Rupee)

Table 4.5: Regime-wise Impact of Local Economic Policy Uncertainty on Exchange Rate Volatility in BRICS Economies

$\boldsymbol{Variables}$	$\boldsymbol{\sigma_{Brazilian\ Real}}$	$\boldsymbol{\sigma_{Russian\ Ruble}}$	$\boldsymbol{\sigma_{Indian\ Rupee}}$	$\boldsymbol{\sigma_{Chinese\ Yuan}}$
$\boldsymbol{Constant}$	-1.8971* (1.0210)	-0.0785 (0.4099)	-0.4194** (0.2114)	0.0050 (0.0064)
$\boldsymbol{\sigma_{1-month\ mean}}$	0.7621*** (0.0951)	0.8380*** (0.1320)	0.6108*** (0.1468)	0.0594 (0.1375)
$\boldsymbol{\sigma_{3-month\ mean}}$	-0.2467** (0.1233)	-0.5093** (0.2282)	-0.0295 (0.1239)	-0.1010 (0.1888)
$\boldsymbol{\sigma_{6-month\ mean}}$	0.0470 (0.0875)	0.0950 (0.1874)	-0.0130 (0.1750)	0.0370 (0.5059
$\boldsymbol{\sigma_{12-month\ mean}}$	-0.0321 (0.0789)	-0.5475* (0.2974)	-0.0068 (0.1345)	-0.0148 (0.4297)
$\boldsymbol{D1 * Local_{EPU}}$	0.4949** (0.2378)	0.0357 (0.0889)	0.1143** (0.0528)	0.0022 (0.0020)
$\boldsymbol{D2 * Local_{EPU}}$	0.4888** (0.2364)	0.1473* (0.0886)	0.1103** (0.0451)	0.0047 (0.0029)
$\boldsymbol{D3 * Local_{EPU}}$		0.1678* (0.0911)		
$\boldsymbol{D4 * Local_{EPU}}$		0.8760*** (0.2903)		
$\boldsymbol{Adjusted\ R - Squared}$	0.4371	0.8000	0.4733	0.2730

*Note: ***, ** and * indicates significance at 1 percent, 5 percent and 10 percent level. Standard errors are presented in the brackets.*

are positively affected by own monthly volatility while the volatility of Brazilian Real and Russian Ruble are negatively affected by own quarterly volatility. Moreover, the volatility of Russian Ruble is also negatively affected by own yearly volatility. These results, along with those in the previous sub-sections, thus show while increases in own monthly volatility increases exchange rate volatility in most BRICS economics, own quarterly volatility tend to negate the observed positive impact of own monthly volatility.

The table also shows that the own EPU is having positive and significant effects on the volatility of Brazilian Real during both the regimes. The volatility of Indian Rupee is also positively affected by own EPU in both the regimes. In case of Russian Ruble, however, positive effects of own country EPU on exchange rate volatility can be observed only in second, third and fourth regimes. However, the volatility of the Chinese Yuan remains unaffected by own volatility as well as local EPU in both the regimes.

The Brazilian Real was in a freely floating regime till September 2008 and a *de-facto* moving band of +/-5 percent thereafter. After the collapse of Lehmann Brothers and the global financial crisis, the monetary authorities altered the exchange rate regime to a moving band of +/-5 percent so as to counter the effect of global financial crisis on the exchange rate. The Brazilian economy also faced a number of economic and political uncertainties since 2008 including the Real appreciation, tax cuts and trade restrictions in 2012, Petrobras scandal in 2014, the mass protests and the acceptance of the request to impeach President Rousseff by Chamber of Deputies in 2015, prosecution of top political leaders and the weak meat scandal in 2017. These events impacted the foreign exchange market of Brazil, as evident from Figure A4.1 (Appendix 4.I), with a sudden jump in volatility of the Brazilian Real in 2008-09 and thereafter from the latter part of 2014 to

2017, albeit at lower magnitude. It is also apparent from the figure that the change of exchange rate regime to a moving band of +/-5 percent after 2008 led to a partial containment of volatility in the exchange market that was triggered by the series of events that occurred in Brazil during that period.

In case of Russian Ruble, the monetary authorities altered the exchange rate regime five times during 2006-2018, as evident in Table 1.1 (Chapter 1). To mention, the Russian Ruble was in a regime of *de-facto* crawling peg till September 2008 and it was sequentially changed to *de-facto* moving band of +/-5 percent, *de-facto* crawling band that is narrower than or equal to +/-5 percent, freely falling and again to *de-facto* crawling band that is narrower than or equal to +/-5 percent. With the onset of global financial crisis in 2008, the exchange rate regime was changed to *de-facto* moving band of +/-5 percent till December 2012. In addition to the global financial crisis, the change in exchange rate regime acted as cushion to uncertainties originating because of State Duma elections in 2011, the protest against fraud in election and the presidential election in 2012. In January 2013, the exchange rate regime was changed to *de-facto* crawling band that is narrower than or equal to +/-5 percent upto October 2014, which helped to control volatility in the foreign exchange markets occurring on account of the Taper Tantrum by Fed, the Ukrainian-Russian conflict and the accession of Crimea by Russia in March 2014. The observed changes in exchange rate regime can possibly explain the changes in currency volatility.

The Russian monetary authorities moved into a freely falling exchange rate regime from November 2014 and continued till February 2016. During this period, there was a sharp devaluation in Russian Ruble which led to the loss of confidence in the

Russian economy and forced the investors to sell off Russian assets leading to a financial crisis. Apart from this, there were international economic sanctions on Russia following the military invasion in Ukraine and the accession of Crimea. The huge fall in crude oil prices in 2014 also led to a decline in the Russian economy as crude oil is a major export of Russia. On the other hand, the devaluation in Russian Ruble put an additional pressure on the Russian companies to make interest payments on debts denominated in US Dollars or foreign currencies that have strengthened against the Ruble. In March 2016, the Russian exchange rate devalued more than 70 percent of its value in October 2014. In response, the monetary authorities changed the exchange rate regime back to De facto crawling band that is narrower than or equal to +/-5 percent which resulted in the control of volatility of the Ruble.

The Indian currency was in a *de-facto* crawling band that is narrower than or equal to +/-2 percent between April 2006 and February 2009. The onset of the global financial crisis in 2008 eroded the confidence of the investors leading to the large withdrawal of foreign portfolio investments from India and in the process depreciating the exchange rate and affecting the volatility of the Rupee, as can be seen from the Figure A4.1 (Appendix 4.I). In order to minimize the observed currency volatility, the monetary authority maintained the exchange rate regime at crawling band +/-2 percent till February 2009. As the volatility lowered in the first half of 2009, the monetary authority relaxed the exchange rate regime to *de-facto* crawling band that is narrower than or equal to +/-5 percent which continued till November 2012. However, the emergence of the Eurozone Sovereign Debt crisis in 2009 and thereafter its spread to other major European economies in 2011 compelled the monetary authorities to further revise their exchange

rate regime. The Eurozone crisis also affected the Indian economy by impacting on exports, capital outflows and withdrawal of FIIs, thereby contributing to a depreciating exchange rate and increasing volatility in the foreign currency. On account of this, the exchange rate regime was further revised back to *de-facto* crawling band that is narrower than or equal to +/-2 percent from December 2012. This revision was effective enough to control the volatility in the exchange market as is evident from the figure.

In case of Chinese Yuan, the exchange rate regime was in a pre-announced crawling peg; de facto moving band narrower than or equal to +/-1 percent from April 2006 to November 2014. The global financial crisis in 2008, the Eurozone debt crisis in 2011 and the US federal Government shutdown in 2013 created an atmosphere of economic and political uncertainty in China. Figure A4.1 (Appendix 4.I) shows that these events could neither significantly influence the foreign exchange market nor the exchange rate volatility as the monetary authorities choose to maintain the regime within a band of +/-1 percent. The exchange rate regime changed to *de-facto* crawling peg in December 2014 and then the subsequent occurrence of Brexit referendum in 2016, the European general election in first half of 2017 and the emergence of US-China trade war in 2018 had effected, though not significantly, the exchange rate volatility of Yuan. This analysis further reveals that Chinese monetary authority control exchange rate more effectively as compared to other BRICS nations, thereby preventing any unprecedented appreciation or depreciation that destabilises the economy.

Table 4.6 illustrates that the volatility of the Brazilian Real, Russian Ruble, Indian Rupee and South African Rand are positively affected by own monthly volatility while the volatility of Brazilian Real, Russian Ruble and South African Rand are negatively

affected by own quarterly volatility. This result re-affirms that while own monthly volatility increases exchange rate volatility in BRICS countries, own quarterly volatility reduces it.

Furthermore, the volatility of Russian Ruble is also negatively affected by own yearly volatility. It is also observed from the table that US EPU has no effect on the volatility of Brazilian Real. The US EPU positively affects the exchange rate volatility of Russian Ruble and Indian Rupee in fourth regime and second regime. It is interesting to note that the US EPU significantly affects volatility of the Chinese Yuan in both the regimes. These results, taking into account the regime dummies, are more nuanced than

Table 4.6: Regime-wise Impact of US Economic Policy Uncertainty on Exchange Rate Volatility in BRICS Economies

$\boldsymbol{Variables}$	$\boldsymbol{\sigma_{Brazilian\ Real}}$	$\boldsymbol{\sigma_{Russian\ Ruble}}$	$\boldsymbol{\sigma_{Indian\ Rupee}}$	$\boldsymbol{\sigma_{Chinese\ Yuan}}$	$\boldsymbol{\sigma_{South\ African\ Rand}}$
$\boldsymbol{Constant}$	-3.2570 (2.7356)	-0.0522 (0.8745)	-0.2326 (0.1653)	-0.0070 (0.0092)	-2.2396 (1.8813)
$\boldsymbol{\sigma_{1-month\ mean}}$	0.7880*** (0.0986)	0.8725*** (0.1343)	0.6370*** (0.1685)	0.0543 (0.1347)	0.8200*** (0.1220)
$\boldsymbol{\sigma_{3-month\ mean}}$	-0.3057** (0.1316)	-0.4400* (0.2250)	-0.0137 (0.1373)	-0.0870 (0.1819)	-0.3927** (0.1568)
$\boldsymbol{\sigma_{6-month\ mean}}$	0.1014 (0.0827)	0.0339 (0.1838)	-0.0650 (0.2002)	-0.0166 (0.4918)	0.1479* (0.0789)
$\boldsymbol{\sigma_{12-month\ mean}}$	-0.0143 (0.0574)	-0.6214* (0.3321)	0.1167 (0.1868)	0.0636 (0.4337)	0.0365 (0.0761)
$\boldsymbol{D1 * US_{EPU}}$	0.8219 (0.6303)	0.0318 (0.1951)	0.0620 (0.0377)	0.0046* (0.0026)	0.5688 (0.4140)
$\boldsymbol{D2 * US_{EPU}}$	0.7757 (0.5933)	0.1371 (0.1559)	0.0652* (0.0339)	0.0077** (0.0038)	
$\boldsymbol{D3 * US_{EPU}}$		0.1850 (0.1601)			
$\boldsymbol{D4 * US_{EPU}}$		0.9727*** (0.2887)			
$\boldsymbol{Adjusted\ R - Squared}$	0.4308	0.7846	0.4346	0.2931	0.4602

*Note: ***, ** and * indicates significance at 1 percent, 5 percent and 10 percent level. Standard errors are presented in the brackets*

the ones in the earlier subsection. The results show that US EPU impacts on Russian Ruble, Indian Rupee and Chinese Yuan only in certain exchange rate regimes.

The monetary authorities of individual BRICS nations had switched from one exchange rate regime to another to deal with any kind of uncertainty that affect the functioning of the foreign exchange market. The global financial crisis in 2008 and the Eurozone debt crisis in 2011 induced phases of uncertainty in the US economy, which also percolated in the Indian and Chinese foreign exchange markets as is evident from the rising spectre of volatility in Figure A4.1 (Appendix 4.I). However, the amplitude of fluctuation for Yuan is less as compared to the Rupee. This can be on account of greater intervention in the Chinese foreign exchange market by the monetary authority. Nonetheless, events like Brexit in 2016, the election of Donald Trump in 2016, the US pulling out of the Trans-Pacific Partnership (TPP) Agreement in 2017, the begin of US-China trade war in 2018 and the imposition of tariff on steel and aluminum imports in 2018 also added to the economic and political uncertainty in the US. These incidents also resulted in uncertainties in the foreign exchange market of Russia, India and China. However, the Brazilian and South African foreign exchange markets were insulated from the effects of such uncertainties even though South Africa universally followed a free floating regime during the entire period.

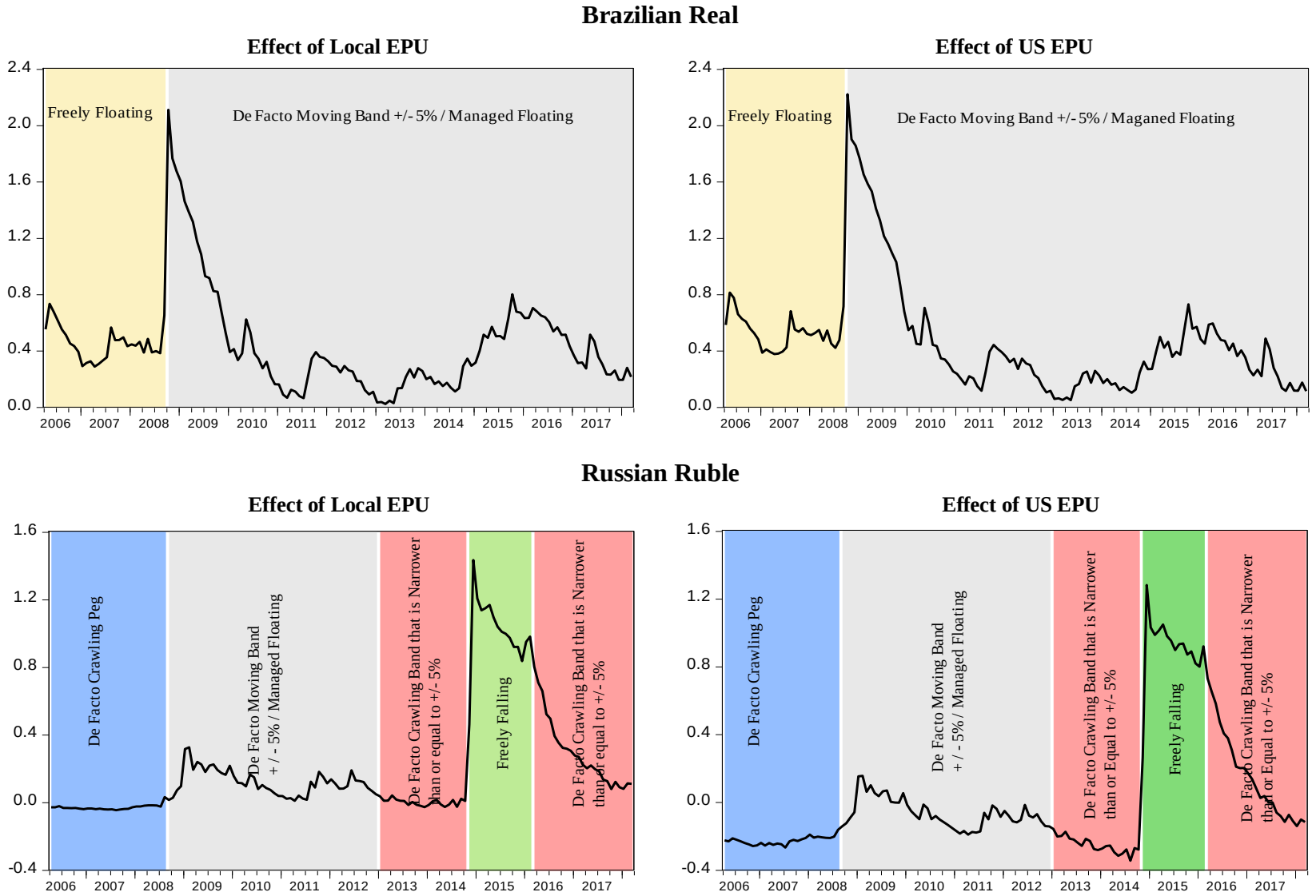
On the whole, estimates of different versions of HAR model are presented. The estimation coefficients are not time varying. But, as discussed in the literature, the effect of policy uncertainties on the volatility of exchange rate cannot be constant overtime. The exchange rate volatility may increase or decrease depending on the degree of uncertainty that a particular country face during the course of time. Besides, these OLS estimates are

mainly a summary of the reactions of the BRICS currency volatility to the economic policy uncertainties, it does not necessarily provide a clear picture of the impact of several domestic/international events that occurred during each exchange rate regime. Moreover, the results of the regime-wise effect of economic policy uncertainty on the volatility of exchange rate may be sensitive to the definition or methodology used to identify the regimes. As the methodology for identifying such regimes change or the definition of regimes change, the result may also change.

To deal with the issue, the flexible least square (FLS) model[11], proposed by Kalaba and Tesfatsion (1989), is estimated to present the dynamic nature of movement in exchange rate volatility in response to economic policy uncertainty. Figure 4.1 show such regime-wise movement of exchange rate volatility with regard to policy uncertainty. It is evident from the figure that the volatility of BRICS currencies has a considerable regime-wise time varying movement in response to shocks generated from economic policy uncertainties at home and abroad. The policy uncertainties induced currency volatility to increase from lower to higher range for all the BRICS economies. For instance, the policy uncertainty at the home country such as Petrobas scandal in 2014 and the meat scandal in 2017 in Brazil, the State Duma elections in 2011 and the imposition of economic sanctions in 2014 in Russia or the capital outflows from India in 2012 led to an increase in exchange rate volatility of Brazilian Real, Russian Ruble and Indian Rupee respectively during these periods. On the other hand, the international events like the global financial crisis in 2008 has increased the Real and Rand volatility, while the Eurozone debt crisis in 2011, the Brexit Referendum in 2016 and the US-China trade war in 2018 largely impacted the Rupee and Yuan volatility. The graphs also reveal that own

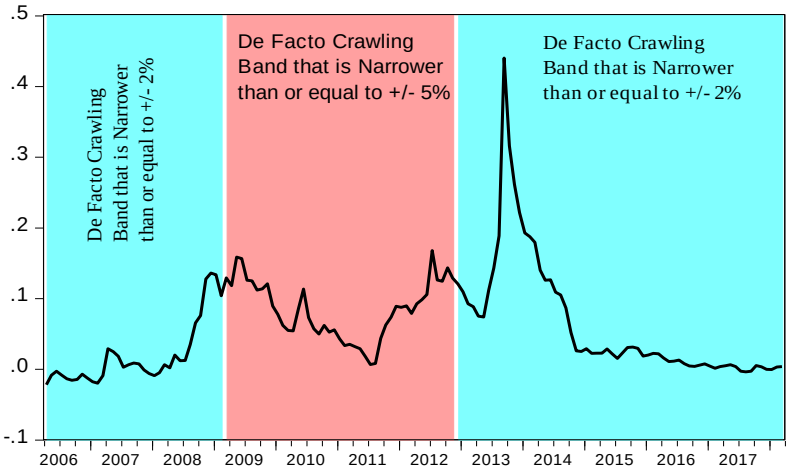
[11] The method of Flexible Least Square estimation is described in Appendix 4.II.

Figure 4.1: Time Varying Movement of Exchange Rate Volatility with Economic Policy Uncertainties

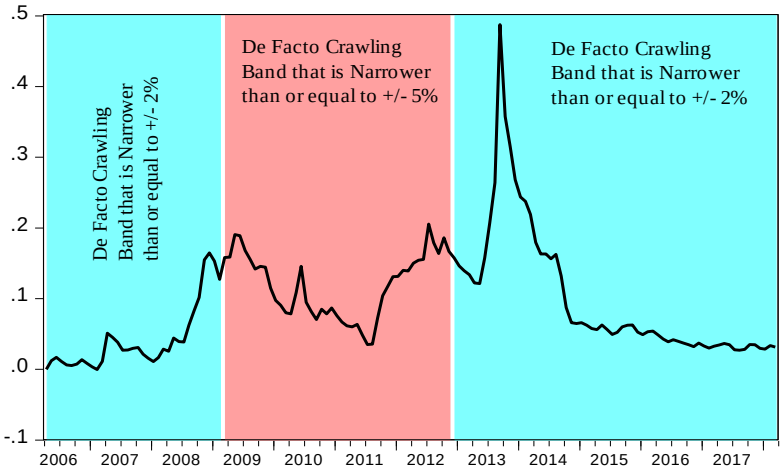


Indian Rupee

Effect of Local EPU

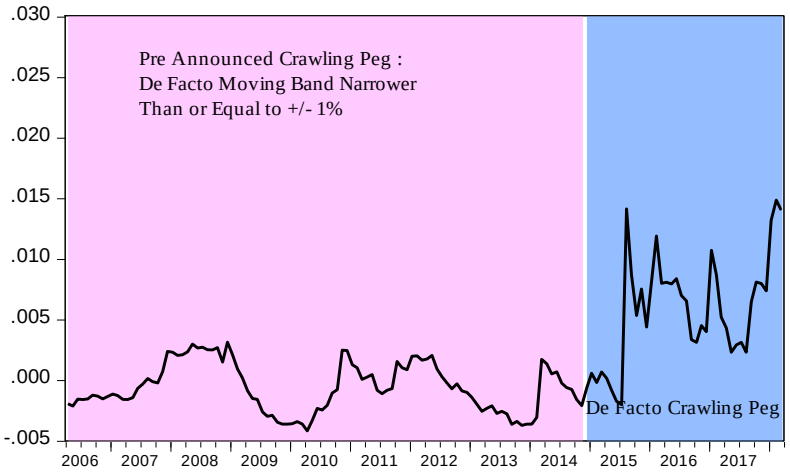


Effect of US EPU

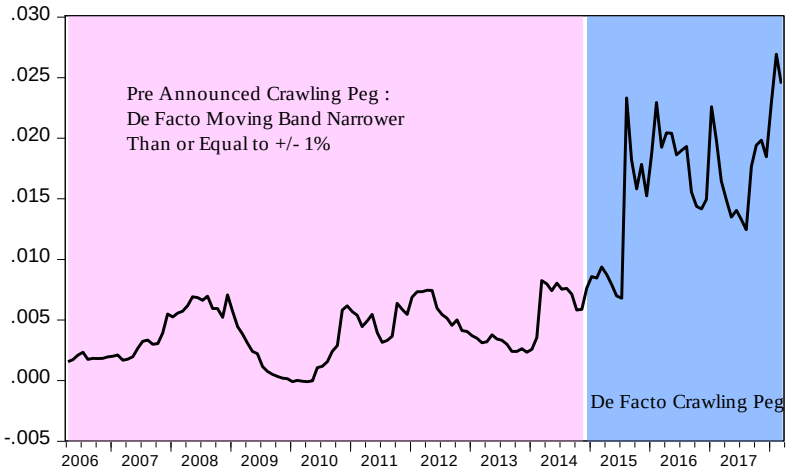


Chinese Yuan

Effect of Local EPU

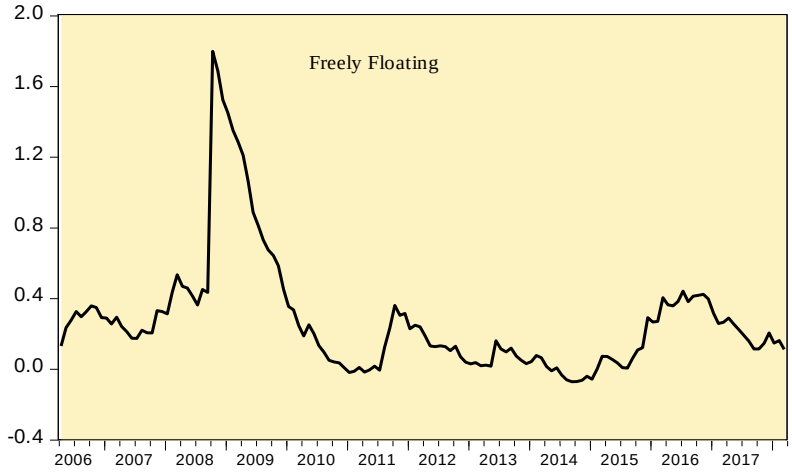


Effect of US EPU



South African Rand

Effect of US EPU



EPU has a greater effect on the Brazilian and Russian currency volatility whereas the effect of US EPU on the volatility of Indian Rupee and Chinese Yuan is higher than own EPU. These findings support the estimates presented in Tables 4.5 and 4.6.

4.4.4 In-sample forecasting performance

In the following section, the in-sample forecast performance has been analysed for the period 2006 to 2018. The evaluation of in-sample forecast performance has been done in terms of three tests, which would necessarily confirm the appropriateness of the model of estimation by predicting the known values of the observations. In this section, the in-sample forecasting performance of the model is presented in Table 4.7, Panel (A to D). Five models have been estimated to compare their forecasting performances. Here, model 1, the base line model, is the simple ARIMA model. The appropriate order of the ARIMA model has been determined using Schwarz Information Criterion (SIC). The model 2 is the ARFIMA model. Model 3, Model 4 and Model 5 are the simple HAR model, HAR model along with EPU as an additional regressor, and HAR model along with EPU and exchange rate regimes as additional regressors, respectively. Here, for the purpose of comparison, models are categorized into two types: restricted and unrestricted models. The model with lesser number of predictors/ regressors is called a restricted model and the model with relatively more number of predictors/regressors is called an unrestricted model. In Table 4.7, Panel (A to D), models in the columns are the unrestricted models whereas the models in the rows are the restricted models.

For the purpose of forecast evaluation, three tests namely, the Campbell-Thompson test, the Diebold-Mariano test and the Clark-West test, have been applied. A

Table 4.7: In-sample forecasting performance

Panel A: Brazilian Real

	Model 2 (ARFIMA)	Model 3 (HAR)	Model 4 (HAR+EPU)	Model 5 (HAR+EPU+Regime)
		Campbell & Thomson (2008) Statistics		
Model 1	0	0.2423	0.2659	0.2659
Model 2		0.2425	0.2659	0.2659
Model 3			0.0312	0.0312
Model 4				0
		Diebold & Marino (1995) Statistics		
Model 1	0.5303	2.1437**	2.1635**	2.1648**
Model 2		2.1442**	2.1640**	2.1653**
Model 3			1.2772	1.2850
Model 4				0.0828
		Clark & West (2007) Statistics		
Model 1	1.4936	18583.74*	20056.71**	20057.47**
Model 2		18581.92*	20053.89**	20054.66**
Model 3			1497.837**	1498.680**
Model 4				1.8731

Panel B: Russian Ruble

	Model 2 (ARFIMA)	Model 3 (HAR)	Model 4 (HAR+EPU)	Model 5 (HAR+EPU+Regime)
		Campbell & Thomson (2008) Statistics		
Model 1	-0.0049	0.4261	0.4369	0.5673
Model 2		0.4289	0.4397	0.5694
Model 3			0.0189	0.2460
Model 4				0.2315
		Diebold & Marino (1995) Statistics		
Model 1	-1.7495*	1.7428*	1.7588*	1.8536*
Model 2		1.7458*	1.7605*	1.8508*
Model 3			0.9352	1.1588
Model 4				1.1728
		Clark & West (2007) Statistics		
Model 1	-343.9813	43117.03*	48117.01**	52327.79**
Model 2		43761.43*	48835.66**	53022.02**
Model 3			5024.088**	9210.443*
Model 4				8412.308*

Panel C: Indian Rupee

	Model 2 (ARFIMA)	Model 3 (HAR)	Model 4 (HAR+EPU)	Model 5 (HAR+EPU+Regime)
		Campbell & Thomson (2008) Statistics		
Model 1	0.0018	0.2422	0.2760	0.2769
Model 2		0.2409	0.2747	0.2456
Model 3			0.0446	0.0458
Model 4				0.0013
		Diebold & Marino (1995) Statistics		
Model 1	0.9734	2.2505**	2.4648**	2.4120**
Model 2		2.2639**	2.4835**	2.4294**
Model 3			1.9216*	1.8998*
Model 4				2.2433
		Clark & West (2007) Statistics		
Model 1	0.8971	468.1948***	515.5322***	516.2934***
Model 2		466.7995***	513.7270***	514.4883***
Model 3			52.9967***	53.7398***
Model 4				1.4951

Panel D: Chinese Yuan

	Model 2 (ARFIMA)	Model 3 (HAR)	Model 4 (HAR+EPU)	Model 5 (HAR+EPU+Regime)
		Campbell & Thomson (2008) Statistics		
Model 1	-0.0023	0.1248	0.1278	0.1665
Model 2		0.1268	0.1298	0.1684
Model 3			0.0034	0.0477
Model 4				0.0444
		Diebold & Marino (1995) Statistics		
Model 1	-0.4138	2.8160***	2.9112***	2.5047**
Model 2		3.0124***	3.1523***	2.7425***
Model 3			0.4173	0.6869
Model 4				0.7065
		Clark & West (2007) Statistics		
Model 1	-0.1745	1.9416***	2.4234***	2.5515***
Model 2		2.3787***	2.8453***	2.9733***
Model 3			0.1529**	0.2810
Model 4				0.2520

positive Campbell-Thompson test statistics indicates that the unrestricted model produces better forecast than the restricted model. On the other hand, a positive and significant Diebold-Mariano test and Clark-West test statistics imply that the unrestricted model can

forecast exchange rate volatility better than the restricted model. From panel A, Table 4.7, it can be seen that the variants of the HAR model (Model 3, Model 4 and Model 5) perform better than the ARIMA model and ARFIMA model. Furthermore, it can be seen that while forecasting implied volatility of Brazilian Real–US Dollar exchange rate, it is important to incorporate economic policy uncertainty, but the inclusion of exchange rate regimes does not necessarily improve the forecasting performances of HAR model. The Diebold-Mariano test and Clark-West test statistics confirm the above proposition. From Panel B and Panel C of Table 4.7 it can be seen that to model Russian Ruble-US Dollar exchange rate volatility and Indian Rupee-US Dollar exchange rate volatility, it is important to include both economic policy uncertainty as well as exchange rate regime dummy as predictors. The same results are also found in case of Chinese Yuan-US Dollar exchange rate volatility.

4.5 SUMMARY OF FINDINGS

This essay has investigated into the impact of local and US economic policy uncertainty on exchange rate volatility of BRICS economies. The empirical results show that the exchange rate volatility of the BRICS countries are primarily dependent on own recent past volatility. The Brazilian Real and Indian Rupee are mostly affected by own EPU whereas the US EPU affects the Indian Rupee only. The BRICS foreign exchange markets are found to have switched policy regimes to which the local and US EPUs responded differently. For instance, the local EPU affects the volatility of Brazilian Real and Indian Rupee in both the regimes, while it impacts on the Russian Ruble in second, third and fourth regimes. Chinese Yuan is an exception to this pattern.

On the other hand, the US EPU affects the Russian Ruble in fourth regime, Indian Rupee in second regime and Chinese Yuan in both regimes. The effects of local and the

US economic policy uncertainty was low in case of Chinese Yuan, which is indicative of the Chinese monetary authority regulating on the foreign exchange market. While some previous studies find that, for emerging market economies, exchange rate volatility is caused by own economic policy uncertainties, this study has shown that currency volatility in Russia, India and China has been largely predicted by US economic policy uncertainty as well. Moreover, the FLS model estimation also reveals the dynamic response of regime-wise BRICS exchange rate volatility with regard to the EPUs. Nonetheless, the in-sample forecast performance necessarily confirms the appropriateness of these models of estimation.

APPENDIX 4.I

Figure A4.1: Time Pattern of BRICS Currency Volatility

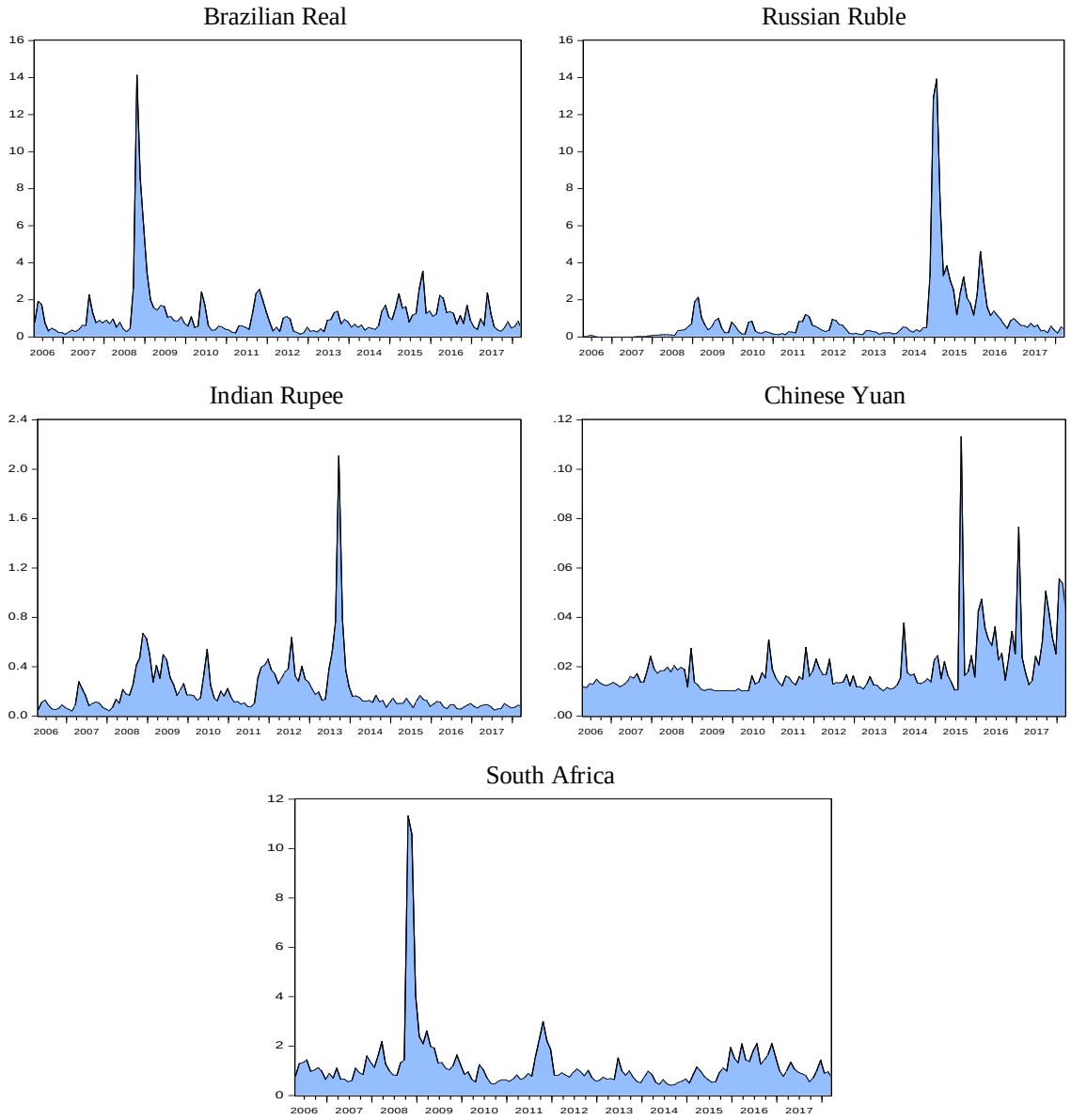
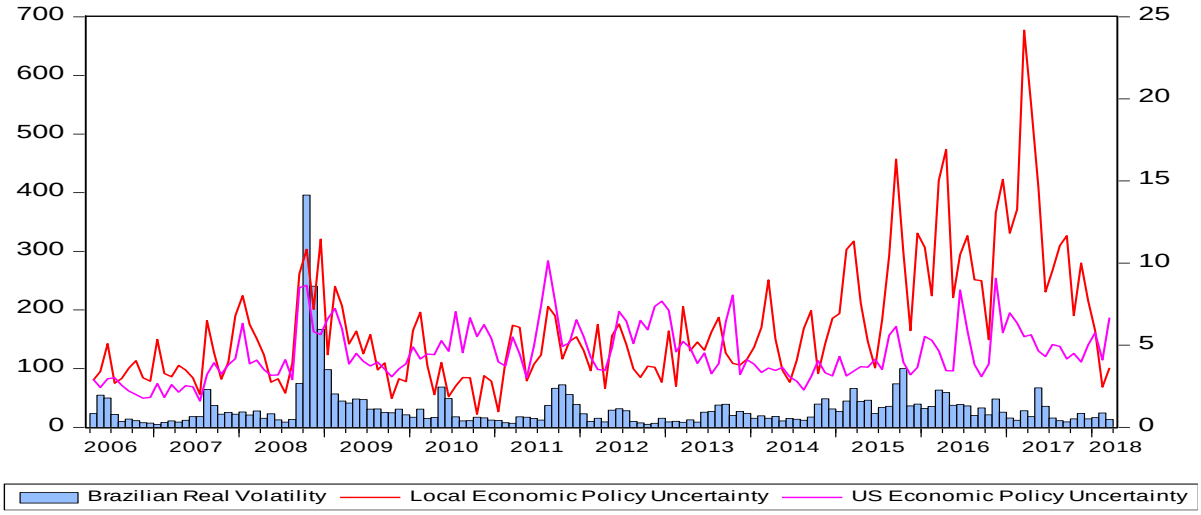
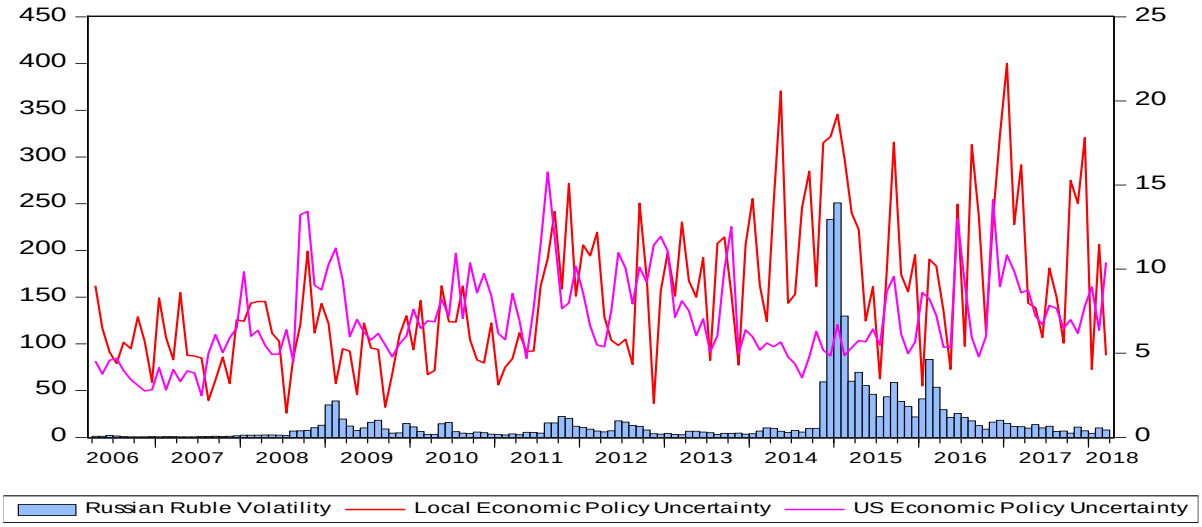


Figure A4.2: Time Pattern of BRICS Currency Volatility and Economic Policy Uncertainties

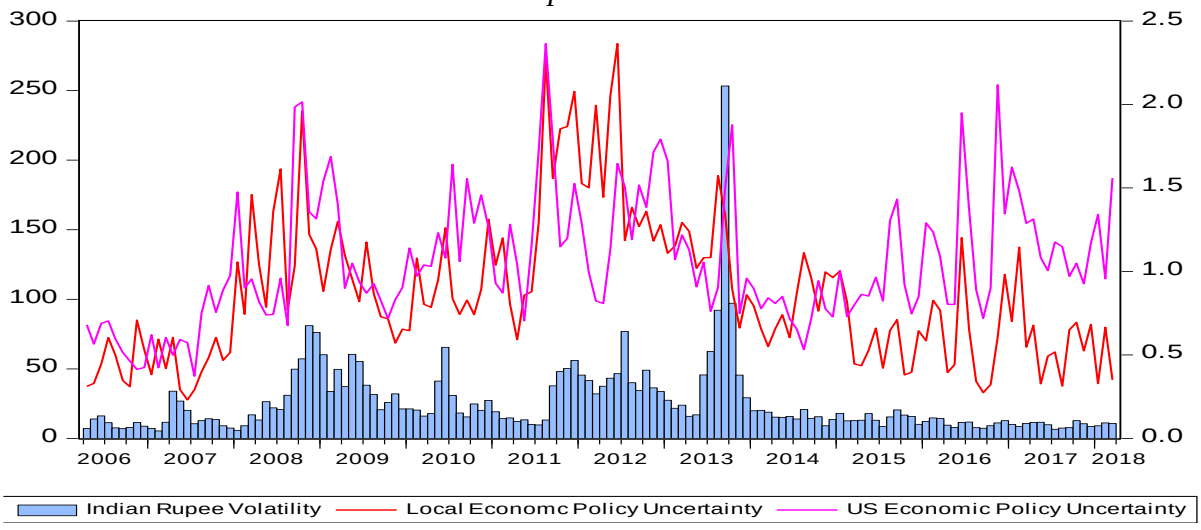
Brazilian Real with EPUs



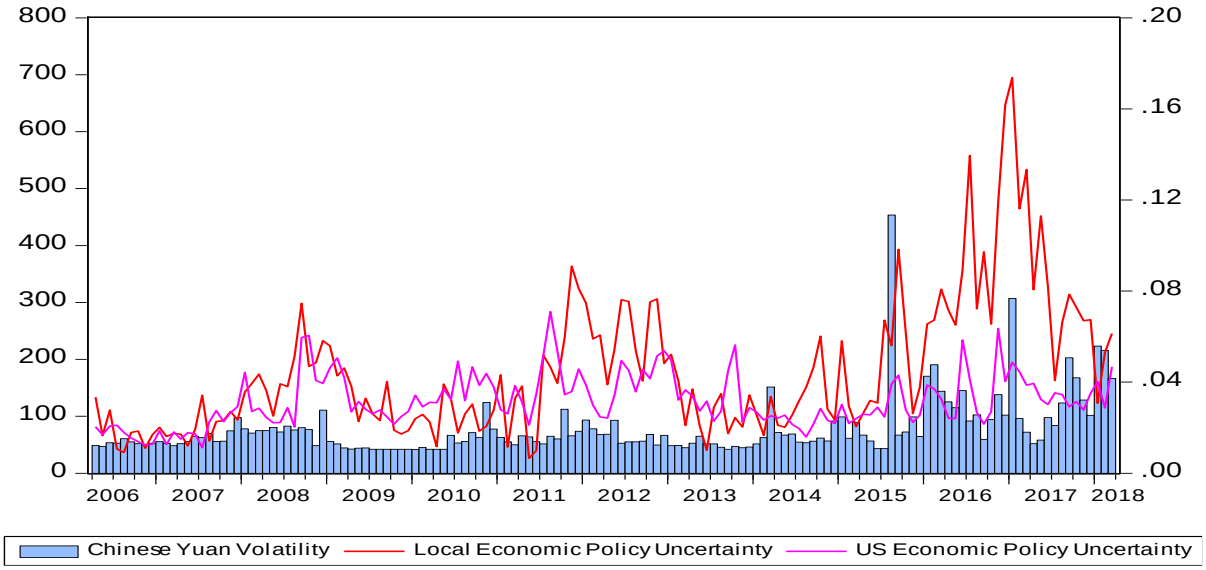
Russian Ruble with EPUs



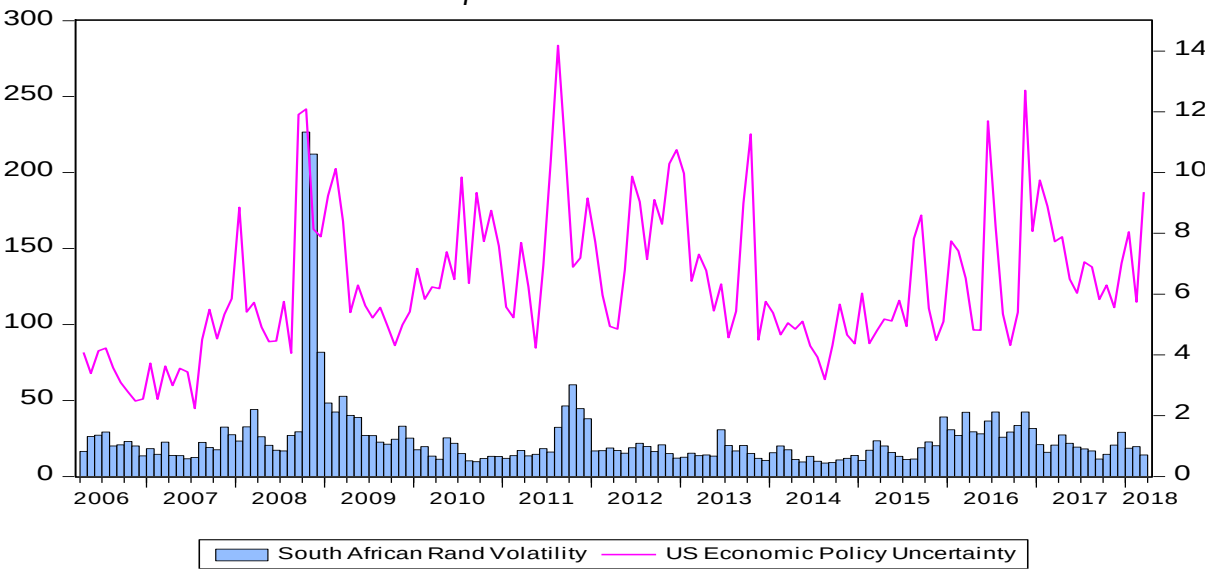
Indian Rupee with EPUs



Chinese Yuan with EPUs



South African Rand with US EPU



APPENDIX 4.II

Methodology for Flexible Least Square Approach

The time varying linear regression problem was put forward by Kalaba and Testfatsion (1989). Suppose noisy observations $y_1, \ldots\ldots, y_N$ over a time-span $1, \ldots., N$ are assumed to have been generated by a linear regression model with coefficients that evolve only slowly over time, if at all. More precisely, these prior theoretical beliefs take the following form:

Prior Measurement specification (linear measurement):

$$y_n - x_n^T b_n \approx 0; n = 1, \ldots\ldots., N \quad \ldots\ldots\ldots(1a)$$

Prior Dynamic specification (coefficient stability):

$$b_{n+1} - b_n \approx 0; \; n = 1, \ldots\ldots., N-1 \quad \ldots\ldots\ldots(1b)$$

where $x_n^T = (x_{n1}, \ldots\ldots, x_{nk}) = 1 \times K$ row vector of known exogenous regressors and

$b_n = (b_{n1}, \ldots\ldots, b_{nk})^T = K \times 1$ column vector of unknown coefficients.

The measurement and dynamic specifications (1) reflect the prior beliefs of linear measurement and coefficient stability in a simple direct way, without augmentation by any stochastic restrictions.

A basic problem is then to determine whether this theory is compatible with the data. That is, does there exist any coefficient sequence estimate $(b_1, \ldots\ldots., b_T)$ so that the theoretical specifications (1) in an acceptable approximate sense for the realized sequence of observations $(y_1, \ldots\ldots., y_N)$? How might such a coefficient sequence estimate be found? The flexible least squares approach provides a means for finding such coefficient estimate sequence.

***The basic Flexible Least Square (FLS) approach*:**

Two kind of model specification error can be associated with each possible coefficient sequence estimate $b = (b_1, \ldots\ldots, b_N)$ for model (1). First, b could fail to satisfy the prior measurement specification (1a). Second, b could fail to satisfy the prior dynamic specification (1b).

Suppose the cost assigned to b for the first type of error is measured by the sum of squared residual measurement errors:

$r_M^2(b;N) = \sum_{t=1}^{N}[\,y_n - x_n^T b_n]^2$ .....(1c)

and the cost assigned to b for the second type of error is measured by the sum of squared residual

dynamic errors:

$r_D^2(b;N) = \sum_{n=1}^{N-1}[\,b_{n+1} - b_n]^T[b_{n+1} - b_n]$ .....(1d)

Then the (time N) residual possibility set is defined as the collection

$P(N) = \{r_D^2(b;N), r_M^2(b;N) | b \in E^{NK}\}$ .....(1e)

of all possible combinations of squared residual dynamic error and measurement error sums attainable at time N, conditional on the given observations $(y_1, \ldots\ldots, y_N)$. The residual possibility set is depicted in figure 1a.

If the prior theoretical specifications (1) are correct, the squared residual errors associated with the actual coefficient sequence will be approximately zero. In general, however, the lower envelope of the residual possibility set $P(N)$ represents the locus of vector minimal sums of squared residual dynamic and measurement errors attainable at time N, conditional on the given observations (figure 1b). This lower reveal the cost in terms of residual measurement error that must be paid in order to achieve the zero residual dynamic error (time-constant coefficients) required in OLS estimation. Henceforth, this lower envelope, denoted by $P_F(N)$ will be referred to as the (time N) *residual efficiency*

frontier. The coefficient sequence estimates b which attain this frontier are referred to as *FLS estimates.*

For the given observations, the FLS estimates are the coefficient sequence estimates which are *minimally incompatible* with the linear measurement and coefficient stability specifications of (1). Thus, formally, the flexible least squares estimation is finding the coefficient sequence estimates b which minimizes the following "incompatibility cost function

$$C(b;\mu,N) = \mu \sum_{n=1}^{N-1}[b_{n+1} - b_n]^T[b_{n+1} - b_n] + \sum_{n=1}^{N}[y_n - x_n^T b_n]^2 \quad \ldots.(1f)$$

where μ is the weight which gives a relative priority to the two priors in the model specification (1a, 1b). The incompatibility cost function $C(b;\mu,N)$ generalises the goodness of fit criterion function for OLS estimation by permitting the coefficient vectors b_n to vary overtime. The OLS can be viewed as a limiting case of FLS in which absolute priority is given to the dynamic prior (1b) over the measurement prior (1a) (Kalaba and Testfatsion, 1989). The OLS solution can also be interpreted as a particular way of aggregating the information embodied in the FLS estimates $(b_1, \ldots\ldots, b_t)$. Therefore, a key difference between FLS and OLS is that the FLS approach seeks to understand which coefficient vector actually obtained at each time n and the OLS approach seeks to understand which coefficient vector obtained on average over time.

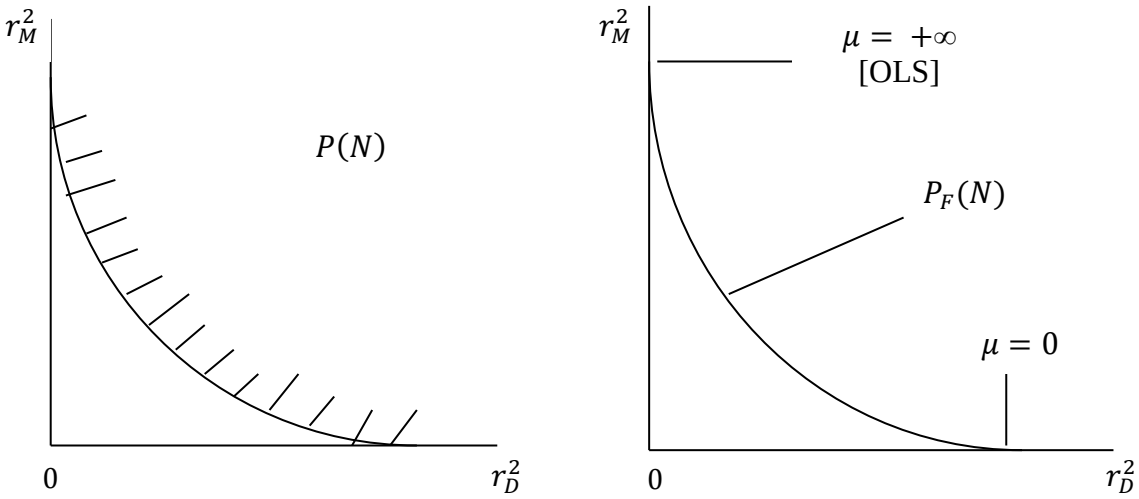


Fig 1(a) Residual possibility set $P(N)$, (b) Residual possibility set $P_F(N)$

CHAPTER 5
Conclusions

Exchange rate is a key macro-finance variable that helps an open economy to achieve equilibrium. The stability of exchange rate is considered important in achieving high economic growth. A strong foreign exchange market has important implications for economic policies and international capital budgeting decisions as well. Currency markets are also believed to have relevance for the investors and policy makers. An unstable exchange rate, on the other hand, can adversely affect the open economy by changing the international price of goods or assets.

Exchange rate volatility can be a source of instability. Exchange rate volatility is traditionally associated with changes in exchange rate regime from a fixed to a free floating one. Exchange rate volatility has become all the more important post globalization, especially for emerging market economies including the BRICS. Through direct and indirect channels exchange rate volatility negatively affects households and firms. The extent and persistence of currency volatility adversely affects, directly or indirectly, a number of key policy variables, including interest rate, returns on investment and, hence growth. Volatility in exchange rate can arise from three possible factors: volatility in market fundamentals, changes in expectations due to new information and speculative “bandwagons”. Any misalignment in the exchange rate thus requires intervention in the foreign exchange market. Managing currency volatility, by keeping a close watch on fundamentals, is thus a major policy challenge for central bank while formulating monetary policy.

With structural changes in the global economy, the emerging market economies, the BRICS in particular, have emerged important with rising share in world GDP, trade, capital inflows, stock market capitalization, and foreign exchange market turnover. The improving economic prospects of BRICS countries attracted investors and portfolio managers to the foreign exchange markets of these countries. Despite emerging strong globally, volatility in currency markets is a possibility in these countries with them getting financially integrated and adopting a regime of more flexible exchange rates. The stylized evidence on exchange rate volatility show (Chapter 1) that the exchange rates of BRICS currencies with respect to the US$ fluctuated during the period since 2006, with all the return series exhibiting high volatility and volatility clustering during the entire sample period, especially after the global financial crises. This finding possibly suggests that the observed volatility pattern across BRICS currencies for a large part of the sample period can be either on account of some domestic or external shocks arising out of the changes in exchange rate policy regimes, uncertainties arising out of other policy changes or the spillover effect of some crises that originated elsewhere in the global economy.

This thesis is set out as a collection of essays on three important aspects of exchange rate volatility in the BRICS economies. The first essay, using Markov switching autoregressive model, has investigated the pattern of regime switching behaviour in currency volatility in the BRICS countries. In specific, the extent and persistence of bullish and bearish regimes are looked into. An estimation of exchange market pressure (EMP) of individual BRICS currencies, in addition, reveals the pressure to appreciate or depreciate along with the need for intervention by the respective central banks to contain such EMP. The second essay deals with volatility transmission, cross-

border or otherwise, with regards to BRICS economies. A study on volatility transmission in the currency has assumed importance ever since exchange rates have become market determined and the pattern of volatility has undergone a distinct change with the possibility of volatility transmission increasing manifold. In specific, the second essay has examined the extent of return co-movement and volatility spillover between BRICS currency markets and some developed country currencies like Euro, Japanese Yen, British Pound and Australian Dollar. Finally, the last essay has explored into the factors determining currency volatility in BRICS economies. In specific, the chapter investigates into the impact of Economic Policy Uncertainty (EPU) on the volatility of BRICS currencies. Applying various Time Series Analysis to the data on daily nominal spot exchange rate for the BRICS countries availed from the Bloomberg database (https://www.bloomberg.com), the essays resort to analyses of three important issues on exchange rate volatility.

The first essay (Chapter 2) has investigated into the regime switching behaviour of the BRICS currencies in a Markov switching framework, and has subsequently estimated the exchange market pressure to identify the phases of appreciation and depreciation and has constructed intervention index to show the degree of intervention by the respective central banks to mitigate the EMP. It is found that Chinese Yuan is the least volatile among BRICS currencies in both bear and bull regimes, whereas South African Rand is the most volatile currency. The foreign exchange markets are affected by several crises, as evident from smoothed probability graphs. Besides, the persistence of the overall cycle across all foreign currency markets in BRICS countries is uniformly higher in the bear regime as compared to the bull regime. In this regard, the Chinese

Yuan is found to have the highest number of cycles in both bear and bull regime suggesting that the currency has gone through maximum phases of appreciation and depreciation as compared to other BRICS currencies. Moreover, the EMP estimates show that the BRICS currencies had gone through a large depreciation phase during the crises periods to which the respective central banks responded with intervention, although the degree was higher for the Chinese central bank than that in other BRICS countries. On the contrary, intervention is the least by the central bank of South Africa.

The econometric analysis has identified that the Chinese Yuan to be attractive among the BRICS currencies to the investors because of its lower volatility in both the regimes although the mean varies across regimes. On the other hand, South African Rand is observed to have a high variance in both the regimes making it unattractive for the investors. Besides, using the smoothed probability obtained from Markov switching model, it is found that there is market synchronization among the BRICS currencies, Chinese Yuan being the exception.

The second essay (Chapter 3) is set out to investigate into the extent of connectedness in foreign exchange markets of BRICS countries with various other countries. In specific, the essay has explored into return co-movement and volatility spillover between BRICS currency markets and some developed country currencies whose turnover of all transactions are high. Using Dynamic Conditional Correlation (DCC) model and Vector Autoregression (VAR) methods, the analyses show the presence of significant return co-movements and volatility spillover between the foreign exchange markets. The econometric analysis identified volatility in the foreign exchange markets of Brazil, India and South Africa have a tendency to persist whereas the foreign

exchange market of Russia and China are explosive in nature as compared to the developed economies. It is also inferred from the analysis that Brazilian Real, South African Rand and Indian Rupee are influenced more by Australian Dollar, while Russian Ruble and Chinese Yuan are influenced more by Euro and British Pound. In addition, BRICS foreign exchange markets, except Brazil and Russia, are net receivers of volatility and developed markets are net transmitter of volatility. The investigation further reveals that South African Rand is the highest receiver of volatility among other BRICS foreign exchange markets. Further, dynamic correlations and volatility spillovers show large variability, which are necessarily synchronous with extreme economic episodes including global recession. The above analysis, however, does not include identification of such movements with major turning points in global economy.

The last essay (Chapter 4) is an exploration of whether economic policy uncertainty impacts on the volatility of BRICS currencies. Using Heterogeneous Autoregressive model, the empirical analysis has shown that the exchange rate volatility of the BRICS countries are primarily dependent on recent past volatility. The Brazilian Real and Indian Rupee are mostly affected by own country EPU whereas the US EPU affects the Indian Rupee only. However, the BRICS foreign exchange markets have switched their exchange rate regimes to which the local EPU and US EPU responded differently. For instance, the local EPU affects the volatility of Brazilian Real and Indian Rupee in both the regimes while Russian Ruble in second, third and fourth regime, leaving Chinese Yuan. On the other hand, the US EPU affects the Russian Ruble in fourth regime, Indian Rupee in second regime and Chinese Yuan in both regimes. The effect of local economic policy uncertainties and the US uncertainties was low in case of

Chinese Yuan which mainly points to the fact that the Chinese monetary authorities maintain a tight control on the foreign exchange market. While some previous studies find that, for emerging economies, exchange rate volatility is caused by its own country economic policy uncertainties, this essay has shown that the currency volatilities in emerging market economies such as Russia, India and China has been largely predicted by US economic policy uncertainties as well.

These results have possibly paved the way for the central banks of the BRICS economies to concentrate more on policy formulation to lower volatility in the foreign exchange markets. The individual BRICS economies have intervened in the respective currency markets to check excess volatility from time to time. Further, with greater global integration of the BRICS nations, the above evidence on return co-movements and volatility spillovers can be of use to investors to effectively participate in currency trading and manage risk through portfolio diversification as well as to policy makers in initiating effective measures to tackle crises in foreign exchange markets. However, as is evident from the market synchronization analysis, there is less opportunity for portfolio diversification as the movements in BRICS currency markets are synchronized, with Chinese Yuan being the exception.

The results further imply that the investors, the monetary authority and the policy makers in the BRICS countries are required to monitor the developments in the foreign exchange markets of the respective developed nations as volatility in the developed country currencies have an impact on the foreign exchange market of BRICS countries. For instance, Brazilian, South African and Indian monetary authority needs to keep an eye on the event taking place in the Australian foreign exchange market as variations in

Australian Dollar affect the Brazilian Real, South African Rand and Indian Rupee. The central banks of Russia and China need to follow the incidents occurring in the foreign exchange markets of Euro and British Pound, as the volatility in these markets influence the volatility in the foreign exchange markets of Russia and China. Such volatility, as Ross (1989) notes, is an important source of information in the financial markets. The first channel of volatility spillover is news which affects a set of financial variables simultaneously (Bollerslev et al. 1992), while the second channel operates through information spillover caused by cross market hedging (Ederington & Lee, 1993).

Moreover, a rise in exchange rate volatility makes it more likely and worthwhile for individuals and firms engaged in international transactions to use costly options to hedge exposures. As a result, risk averse firms may be less inclined to carry out international transactions because of the higher costs associated with trading. Thus, the policymakers are required to be aware of the fact that an increase in uncertainty in the policy arena increases volatility in financial markets and thus negatively affects the performance of the economy. Clarity in economic policy making and its timeliness, especially at the time of crisis or turmoil or recession, can lower economic policy uncertainty and lead to a more stable currency market in the emerging market economies, in general, and the BRICS, in particular.

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