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Influence of Exchange Rate Risk on Exports in BRICS

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ABSTRACT

This study investigates hypothesis that exchange rate risk may have an effect on exports for several emerging market economies namely, Brazil, Russia, India, China and South Africa, which are also called the BRICS. We employ the multivariate GARCH-in-mean model to assess the impact of exchange rate risk on exports. Importantly, this modelling approach follows a single-step procedure which successfully overcomes generated regressor problem. The findings reveal that the real exchange rate volatility has a significant negative impact on exports in Brazil, India, China and South Africa whereas the impact has been found to be positive in Russia. Computed generalized impulse response function suggests that the effects of unexpected shocks of real exchange rate volatility on export growth are more protracted. The innovation shocks of Brazil, Russia and China economies (except India) exchange rate volatility has a positive impact on export uncertainty while foreign income volatility has ambiguously exposing to South Africa economy.

Keywords: Exchange Rate Risk, Export Growth, Multivariate GARCH-in-Mean, GIRF
JEL Classifications: C32, F19, F31

1. INTRODUCTION

The issue of factors affecting international trade is one of the most debated issue in both theoretical and empirical literature. There has been huge literature on the effects of exchange rate risk on international trade over the past few decades. Real world scenarios have also been daily changing just like the number and extent of the studies in this direction. Some of the changes have worsened the exchange rate fluctuation whereas some of them have improved it. Specifically, international trade liberalization along with the huge increase in cross-border financial transactions has actually increased exchange rate risk.[1] For instance, the currency crisis in the developing market economies is a solid example of increasing exchange rate risk. However, on the other hand, several other changes have occurred over the past years that have also served to reduce the unpredictability in exchange rates.

The extensive debate on fixed versus flexible exchange rates started after the collapse of Bretton Woods's system. Opponents of floating exchange rates argue that it may deter trade flows by introducing exchange rate volatility. On the other hand, proponents perceive that flexible exchange rate system can insulate the domestic economy through the foreign shocks. Thus, policy decisions regarding the exchange rate regimes and other policies mainly depend on the determining the true relationship between the exchange rate risk and trade flows. Considering two aspects: first, a main source of risk seems to be originated from the exchange rate fluctuations; and second, a foreign trade has been becoming more significant, and effect of exchange rate risk on export growth should be assessed in the economies under concern.

1 In this study, exchange rate volatility, uncertainty, and risk are used interchangeably.

This study scrutinizes an association between exchange rate risk on export growth in the emerging markets namely, Brazil, Russia, India, China and South Africa, which are also called the BRICS countries. These countries are leading emerging economies and political powers at the regional and international level. Wilson and Purushothaman (2003) predicted that by 2025, the BRICS countries would account for over half the size of the G6 economies (France, West Germany, Italy, Japan, the UK and the US) and in >40 years, they (the BRICS) would be larger than the G6-economies in United States dollar (hereinafter, USD) terms.

Indeed, trade with developing countries is growing three times faster (25% per annum) rather than growth among the developed countries. The BRICS have contributed up to 60% of the trade between low-income countries. As the bulk of this trade is done in USD, the BRICS have accumulated dollar reserves such that today, these countries hold 40% of the World's currency reserves (Sule, 2011). The USD has lost some of its leadership as a stable and strong currency, particularly now with the seemingly every increasing US national debt. This USD instability is an issue of concern for the leaders of the BRICS who have already proposed a move away from the use of the USD as vehicle currency. Most likely, they would use their local currencies in bilateral trade. As a matter of fact, China and Russia have already started to trade using their own currencies. Separately, it is worth noting that there are several reasons to move away from the use of the USD in BRICS countries. First, it would allow BRICS to diversify their foreign reserves as a way of managing the risk. Second, if the BRICS use their national currency to trade and they experience a bright future as predicted, their currencies may become global. Third, it is believed that the use of BRICS currencies would decrease transaction costs compared to the USD. Fourth, this would also allow the BRICS to have a greater political power in international negotiations.

In addition, we have addressed a number of methodological problems. One of the controversial issues in the existing literature is the proxy of the exchange rate risk. Here, it is important to mention that the GARCH family models have sufficiently gained ground in this context and have been proven to be successful in capturing the stochastic properties and stylized facts in financial volatility. Traditionally, conditional mean and conditional variance of exchange rates are estimated separately and incorporated in trade equations in two-step estimation procedure, as most of the previous studies have been done. However, as earlier discussed, this approach might lead to a potential generated regressor problem of inconsistent parameter estimates and biased estimates of coefficients' standard errors (Pagan, 1984; Pagan and Ullah, 1988; McKenzie, 1999, inter alia). This study attempts to resolve this empirical issue by estimating the parameters of the conditional mean function (export equation and exchange rate process) and variance-covariance specification jointly included in an asymmetric and unrestricted multivariate GARCH-in-mean process.

Numerous past studies in this context rely on the two-step procedure. According to the conventional two-step procedure, the risk measure is generated in the first step using different statistical formulae or GARCH-type models then the generated risk measures will be incorporated in trade models in the second step. This conventional approach faces potential generated regressor problem discussed in Pagan (1984). Although, above-mentioned studies tried to investigate the impact of exchange rate risk on export growth within single-step procedure which successfully overcomes generated regressor problem. In particular, we exploit the contemporary multivariate GARCH-in-mean model to assess the impacts of exchange rate risk on export growth. In this new approach, exchange rate risk measure is generated from the second moment equations and simultaneously incorporated in the trade equation which is one of the first moment equations. Novelty of this approach is it takes into account generated regressor issue. Furthermore, we investigate the issue within the relatively new single-step estimation procedure by employing multivariate GARCH-in-mean, and BEKK variance-covariance specification (Hasanov and Baharumshah, 2014). The next minor contribution is an exchange rate volatility modeling. As noted by McKenzie (1999), the relatively new techniques of econometric analysis such as multivariate GARCH-in-mean would appear to have something to offer. So far only a handful of studies have analyzed this issue within the multivariate GARCH-in-mean framework.

The purpose of this study is to improve on the time series regression analysis employed in previous studies by accounting for the time series properties of the determinants and exploiting the multivariate GARCH-in-mean model which should lead to more efficient estimators. According to this approach, by incorporating the conditional variance-covariance specification, the export growth together with an exchange rate volatility are estimated within a single system of equations. Specifically, this study uses a BEKK variance-covariance structure of Engle and Kroner (1995) in the context of exchange rate risk effect on export growth.

Like both theoretical and empirical studies on the linkage between exchange rate risk and trade flow started after the collapse of Bretton Woods system in the early seventies. During the Bretton Woods system, it was an obligation for each country to implement a monetary policy that kept an exchange rate of its currency within a fixed value. After the breakdown of Bretton-Woods agreement several countries started to float their exchange rates. As noted by Baum et al. (2004), the countries that float their exchange rates experienced relatively high fluctuations in their exchange rates. Consequently, the extensive debate on fixed versus flexible exchange rates started and has been continuing until now. One of the arguments against the flexible exchange rates is that the impact of exchange rate volatility might be detrimental to trade flows (Bahmani-Oskooee, 2002).

However, the theories in this context suggest that exchange rate volatility might have a negative, positive or ambiguous impact on export growth. The studies by Clark (1973), Hooper and Kohlhagen (1978), and Akhtar (1984) are the earliest theoretical investigations on the relation between exchange rate risk and foreign trade. These studies arrive at the conclusion of a negative association between exchange rate volatility and trade flows. For instance, to explain the relationship between the series under concer, Clark (1973) develops a model which based on a number of assumptions such as the firm does not utilize imported inputs, the hedging options are not available, the foreign importer pays to the firm in a foreign currency, and the price of commodity is assumed to be an exogenous variable.

A study by Bahmani-Oskooee and Xu (2013) has investigated whether exchange rate uncertainty serves as another determinant of Hong Kong's trade flows. Their investigation is based on ARDL and VAR models. In the paper the issue is still important that it has been in the past, especially if a country is more export oriented. Furthermore, using the data of four CIS countries, Belarus, Kazakhstan, Russia and Ukraine, Hasanov and Baharumshah (2014) have investigated the linkage between exchange rate risk and trade flows over the period for 1998–2008. The results indicated that the exchange rate risk variable was negative in all of the economies under study.

Similarly, Miranda and Mordecki (2015) have investigated how to estimate the impact of exchange rate volatility on export growth for set of countries Brazil, Chile, New Zealand and Uruguay, selected as commodity exporting countries. They further interesting finding is that global demand and international process influence goods' exports for all the selected countries. In the case of Brazil, Chile and New Zealand the authors did not find evidence of real exchange rate volatility impact on export growth. Likewise, Panda and Mohanty (2015) studied the effects of exchange rate volatility on exports in the case of India for the period of 1970–2011. They found that the foreign country's income positively affected to India exports, whereas the domestic exchange rate volatility negatively affected on India exports.

Using the trade function in the context of a multivariate GARCH-in-mean model, Faek et al. (2015) examines exchange rate uncertainty impact on international portfolio export of these countries, Australia, Canada, Euro area, Japan, Sweden and the UK. The authors' general conclusion can be drawn from these results is that exchange rate uncertainty induces risk-averse investors, especially those of the counterparties to the US, to reduce their financial activities and to favor domestic rather than foreign assets in their portfolios in order to minimize their exposure to uncertainty. Grier and Smallwood (2013) investigated the exchange rate shocks and trade of 27 countries over the period from 1973 to 2007. The paper presents a model that effectively combines a reduced form vector autoregression for export growth, foreign income growth, and exchange rate return, with a multivariate GARCH-in-mean model following the dynamic conditional correlation specification of Engle (2002). It is interesting to note that their near universal finding of significant GARCH effects in the real exchange rate shows that fixing nominal exchange rate is not sufficient to avoid from the significant unpredictability of the real exchange rate.

Serenis and Tsounis (2014) studied is to examine whether exchange rate volatility hinders aggregate exports of South Africa, Malawi and Morocco using the error correction method over the period 1973–1990 and also to present a new complexity the issue in hand through the examination of a new measure of exchange rate volatility. A study by Ishimwe and Ngalawa (2015) that focuses an investigate the impact of exchange rate volatility on South Africa's manufacturing exports to the US for the period 1990–2014. The authors compare the studies that are based on EGARCH and error correction models within quarterly data framework.

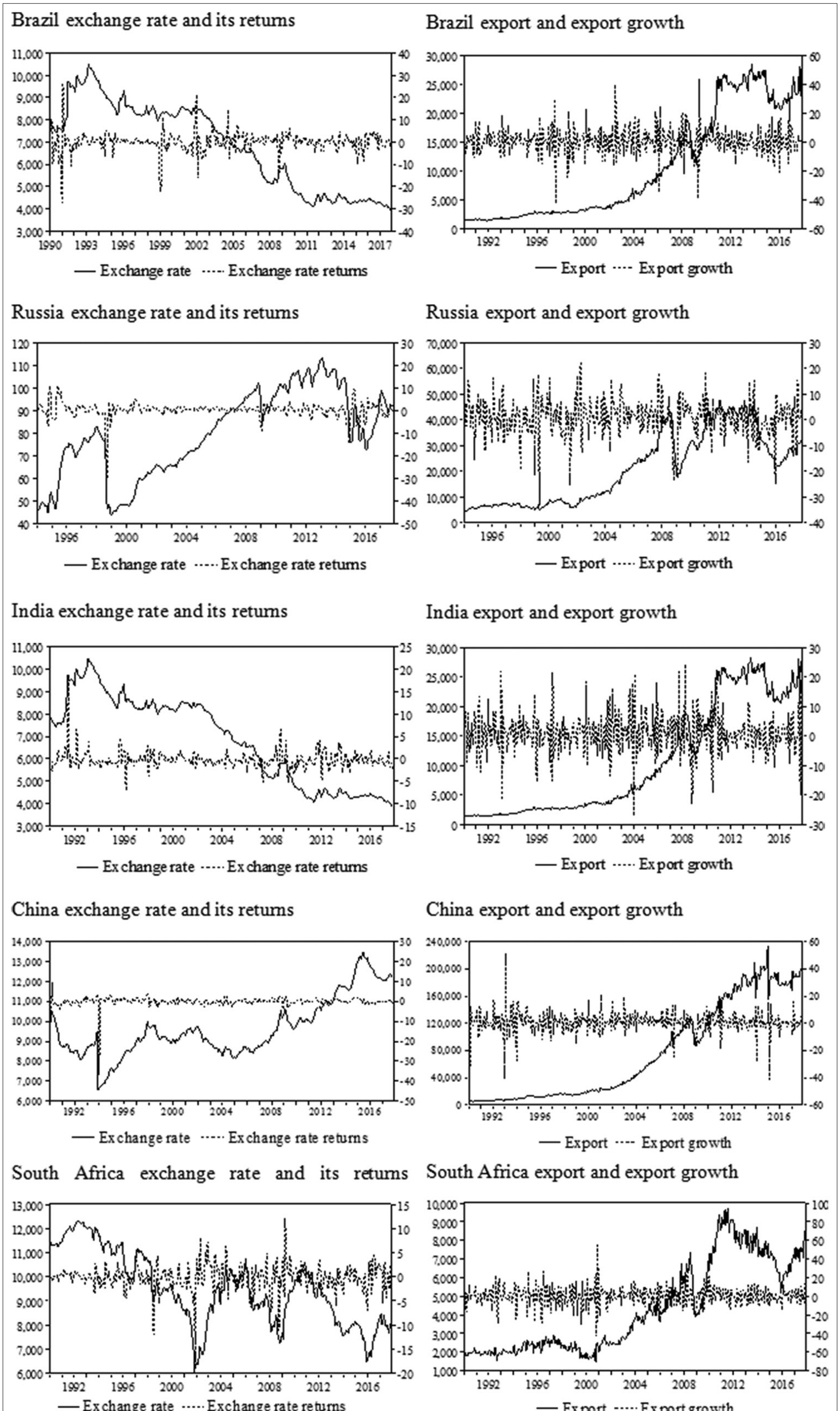
From the literature review presented above, we can conclude that review of theoretical as well as empirical studies which support negative, positive, and ambiguous impact of exchange rate risk on exports. In addition, we have attempted to address some of the important theoretical and empirical points that are crucial in empirical analysis. For example, following the existing literature, we have highlighted the importance of theoretical justification for incorporation of exchange rate risk measure into the trade equations. Moreover, the existing studies that employed single-step estimation approach are also reviewed thoroughly. In conclusion, the review of the literature suggests that most recent studies have been attempting to consider generated regressor issue by focusing on a single-step estimation approach.

1.1. Economic Performances of BRICS Countries

The Global economic leadership is progressively shifting from the G7 to the BRICS, the popular symbol use to refer to Brazil, Russia, India, China and South Africa. Indeed, China passed Japan in 2010 to become the second largest economy, while Brazil just overtook the UK (Dawson and Dean, 2011). The BRICS are first characterized by an astonishing economic growth, from 5% to a two-digit annual growth, depending on the countries. Together, the BRICS represent 30% of the global economic growth, 40% of the world's population and 25% of the global land mass (Sule, 2011). Wilson and Purushothaman (2003) predicted that by 2025, the BRICS countries would account for over half the size of the G6 economies (France, West Germany, Italy, Japan, the UK and the US) and in <40 years, the BRICS would be larger than the G6 in the USD terms. In addition, trade with developing countries is growing three times faster (25% per annum) than among developed countries. The BRICS have contributed up to 60% of the trade between low-income countries. As the bulk of this trade is done in USD, the BRICS have accumulated dollar reserves such that today, these countries hold 40% of the World's currency reserves (Sule, 2011). The USD has lost some of its leadership as a stable and strong currency, particularly now with the seemingly every increasing US national debt. This USD instability is an issue of concern for the leaders of the BRICS who have already proposed a move away from the use of the USD as vehicle currency. Most likely, they would use their local currencies in bilateral trade. As a matter of fact, China and Russia have already started to trade using their own currencies.

Figure 1 depicts graphical illustrations of seasonally adjusted monthly time series and logarithmic transformed data of the real effective exchange rate and export growth of the BRICS countries. As a plotted, the exchange rate returns of Brazil is highly volatile for the sample period, and a structural break is also ensured in 1990–1991, 1998, 2001–2002, 2004, whereas in Russia and China economies the exchange rate returns exhibit relatively high volatility for the sample periods of 1993–1994, 1997–1998, 2014–2015 and 2008–2012. Indeed, India and South Africa's economies exchange rate returns

Figure 1: The data and logarithmic changes of the series for the sample periods



highly volatile for the following sample periods of 1991–1992, 1997–1998, 2001–2002 and 2007–2013, 2015–2016. There is a high possibility that these volatile sample periods are relatively associated with the recent decade's economic and financial downturns.

The reminder of the paper is organized as follows. Next section describes data and summary statistics of the series under concern. Section 3 discusses the econometric methodology. Section 4 outlines the empirical results and their discussion. Finally, Section 5 concludes the study and provides with some policy implications for the economies of interest.

2. DATA AND SUMMARY STATISTICS

This section outlines the data sources and the construction of the variables employed in empirical estimation. The sample period was selected solely on the basis of available real effective exchange rate, export growth, and foreign income data. The data are retrieved from Directions of Trade and International Financial Statistics databases of International Monetary Fund's and the National Bureau of Statistics of China database. The data covers the periods 1990 M1-2017 M12 for Brazil, India, China and South Africa, and 1994 M1-2017 M12 for Russia. Monthly export volumes of selected countries are available in DOT of IMF. Following the vast literature (Qian and Varangis, 1994; Bahmani-Oskooee, 2002; Verheyen, 2012; inter alia) a foreign income measure is incorporated into the export equations.We use the index of industrial production of the economies under concern for the proxy of foreign income. To employ the industrial production as a proxy for foreign income allows the use of monthly data (Verheyen, 2012). Following the recent uncertainty and volatility related works (Fountas et al., 2003; Grier and Perry, 2004; Bredin and Fountas, 2007; inter alia) the employed data was seasonally adjusted to allow for smoothening of any seasonal impacts and to lessen the noise in model. It should be noted that the industrial production reflects only manufacturing index of South Africa economy.

Table 1 reports the summary statistics for the series. The monthly returns for individual countries were constructed as the first differences of the natural logarithm, $R_{i,t}$, as follows

$$R_{i,t} = \ln\left(\frac{K_i}{K_{i,t-1}}\right)\times 100 \qquad (1)$$

Where, subscript i denotes real exchange rate ($K_{r,t}$), export growth ($K_{x,t}$), and foreign income ($K_{f,t}$), respectively. According to the table entries, the averages of monthly returns are smaller than their computed standard deviations in all cases.

As reported, all returns of the series take positive mean values (except the returns of Brazil, India and South Africa's exchange rate). The computed skewness coefficient demonstrates that unconditional distribution of the foreign income is negatively skewed (except the returns of India and Russia foreign income growth). Likewise, exchange rate returns are negatively skewed (except the returns of India exchange rate returns). The negative (positive) skewness coefficients indicate the dominance of negative (positive) values in the sample. Here, two facts should be emphasized. First, the kurtosis coefficients suggest that empirical distribution of the variables is abnormal. There are some excess kurtosis cases in the real exchange rate variables. Second, the rejection of the null of normality is confirmed by the Jarque-Bera (henceforth, J-B) test statistics. All in all, for the sample size considered in this study, the variables seem to be conditionally heteroskedastic. Thus, a multivariate GARCH-in-mean model appears to be suitable in empirical estimation.

In Table 2, the Ljung–Box Q test statistics of Ljung and Box (1978) for serial correlation of the return series and the squared returns

Table 1: Descriptive statistics of the series

Series	Mean	Maximum	Minimum	SD	Skewness	Kurtosis	Jarque-Bera
Brazil							
$K_{r,t}$	−0.0521	25.830	−27.453	4.5384	−0.6160	14.371	1826.1***
$K_{x,t}$	0.5679	42.976	−42.781	9.6360	0.0136	6.6633	187.33***
$K_{f,t}$	0.0990	25.696	−28.883	4.1133	−0.1521	15.827	2298.2***
Russia							
$K_{r,t}$	0.2431	11.031	−41.649	3.7557	−4.9882	56.816	35823.***
$K_{x,t}$	0.7133	22.234	−33.221	7.7271	−0.6722	5.1568	77.248***
$K_{f,t}$	0.1034	15.526	−10.886	2.7197	0.4559	9.7729	558.50***
India							
$K_{r,t}$	−0.2245	18.390	−7.1768	1.9115	3.0012	30.214	10841.***
$K_{x,t}$	0.8703	24.480	−27.036	7.1351	0.0831	4.8048	45.853***
$K_{f,t}$	0.4740	20.022	−13.233	2.8618	0.7103	16.276	2488.4***
China							
$K_{r,t}$	0.0411	9.3078	−36.931	2.4916	−9.8423	147.23	29579.***
$K_{x,t}$	1.0177	52.088	−41.308	8.2193	−0.5733	12.641	1315.8***
$K_{f,t}$	0.0833	24.827	−23.861	4.2675	−0.0920	12.840	1352.1***
South Africa							
$K_{r,t}$	−0.1051	12.201	−17.698	2.7903	−0.9328	9.6533	666.47***
$K_{x,t}$	0.4263	55.129	−43.115	10.640	−0.0068	5.5899	93.632***
$K_{f,t}$	0.0890	9.6901	−9.6094	2.3415	−0.0726	5.4887	86.751***

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively. The data are presented as seasonally adjusted. Here, $K_{r,t}$, $K_{x,t}$, $K_{f,t}$ denote logarithmic changes of the real exchange rate, export and foreign income, respectively series of $K_{r,t}$, $K_{x,t}$, and $K_{f,t}$ are thoroughly detailed. The Q and Q^2 statistics asymptotically follow Chi-squared (χ^2) distribution. We reject the null hypothesis in all cases except the Q^2 of Russia, India, China and South Africa's exchange rate returns. Apparently, the return series exhibit a significant amount of linear dependence and strong evidence of conditional heteroscedastic effects in the series, suggesting the existence of an autoregressive structure in both mean and volatility of the returns. Besides, Brock, Dechert and Scheinkmen (hereinafter, BDS) test statistics for independence proposed by Brock et al. (1996) indicate that all the return series are not independently and identically distributed at the one percent significance level (except Russia and China exchange rate returns).

Since the meaningful GARCH estimations need the stationarity of all exchange rate returns, we initially performed for a unit root tests by using conventional augmented Dickey-Fuller (henceforward, ADF), Phillips–Perron (henceforth, PP) and the Kwiatkowski–Phillips–Schmidt–Shin (henceforward, KPSS) tests for the return series of all economies under investigation. As reported in Table 3, the optimal lags for the ADF and PP tests are selected using Schwarz information criterion (hereinafter, SIC), and the bandwidth for PP and KPSS tests is selected with Newey–West by using the Bartlett kernel. Likewise, in Grier and Perry (2004), the null hypothesis of the KPSS test for stationarity is opposed to the null of a unit root in ADF and PP tests. The robustness of the sample series is established by holding it in level

Table 2: Serial correlation and ARCH test

Series	Q (4)	Q (8)	Q^2 (4)	Q^2 (8)	BDS (8)	ARCH (4)
Brazil						
$K_{r,t}$	8.0340***	14.706***	91.463***	91.654***	0.1246***	40.543***
$K_{x,t}$	105.50***	122.37***	40.879***	44.424***	0.0626***	12.139***
$K_{f,t}$	53.588***	58.820***	94.793***	95.110***	0.0776***	9.8680***
Russia						
$K_{r,t}$	30.642***	34.622***	0.4550	0.4645	−0.0006	0.1030
$K_{x,t}$	15.408***	20.434***	15.703***	17.864***	0.0228***	3.5530***
$K_{f,t}$	29.520***	32.279***	39.106***	40.285***	0.1017***	7.6340***
India						
$K_{r,t}$	15.832***	23.934***	0.2431	4.4639*	0.0765***	0.0590
$K_{x,t}$	67.591***	80.866***	39.434***	41.327***	0.0559***	10.884***
$K_{f,t}$	117.75***	119.07***	96.058***	96.557***	0.0544***	37.111***
China						
$K_{r,t}$	1.3728*	1.9089*	0.0613	0.0793	−0.0005	0.0009
$K_{x,t}$	70.746***	71.466***	40.593***	40.810***	0.0362***	17.347***
$K_{f,t}$	80.894***	82.796***	20.572***	22.806***	0.1170***	11.648***
South Africa						
$K_{r,t}$	11.489***	18.262***	3.4325	14.974***	0.0700***	0.7770
$K_{x,t}$	89.480***	99.232***	48.172***	48.707***	0.0550***	12.249***
$K_{f,t}$	99.526***	121.70***	43.627***	44.537***	0.0648***	14.423***

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively. The data are presented as seasonally adjusted. Here, $K_{r,t}$, $K_{x,t}$, and $K_{f,t}$ denote logarithmic changes of real exchange rate, export and foreign income, respectively

Table 3: Unit root tests

Series	ADF (μ)	ADF (τ)	PP (μ)	PP (τ)	KPSS (μ)	KPSS (τ)	No. obs
Brazil							
$K_{r,t}$	−16.145***	−16.143***	−16.107***	−16.088***	0.0909	0.0467	324
$K_{x,t}$	−22.348***	−22.333***	−34.561***	−34.571***	0.1225	0.1115	324
$K_{f,t}$	−14.967***	−15.010***	−31.881***	−31.655***	0.0898	0.0878	324
Russia							
$K_{r,t}$	−12.082***	−13.093***	−11.844***	−11.833***	0.1068	0.0473	276
$K_{x,t}$	−19.930***	−19.949***	−19.682***	−19.701***	0.1541	0.0703	276
$K_{f,t}$	−16.753***	−16.711***	−21.208***	−21.170***	0.1674	0.1669	276
India							
$K_{r,t}$	−14.808***	−14.897***	−14.853***	−14.883***	0.2298	0.0731	324
$K_{x,t}$	−28.393***	−28.359***	−28.973***	−28.940***	0.1254	0.1159	324
$K_{f,t}$	−19.599***	−19.569***	−37.729***	−37.737***	0.0796	0.0771	324
China							
$K_{r,t}$	−19.588***	−19.616***	−19.557***	−19.586***	0.2469	0.0611	324
$K_{x,t}$	−20.512***	−20.571***	−34.966***	−34.536***	0.1478	0.1250	324
$K_{f,t}$	−7.7034***	−7.7435***	−49.288***	−51.298***	0.3391	0.1174	324
South Africa							
$K_{r,t}$	−15.281***	−15.259***	−15.258***	−15.235***	0.0407	0.0373	324
$K_{x,t}$	−20.914***	−20.886***	−32.847***	−32.802***	0.0768	0.0593	324
$K_{f,t}$	−11.121***	−11.105***	−30.128***	−30.089***	0.0482	0.0392	324

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively. The data is presented as seasonally adjusted. Here, $K_{r,t}$, $K_{x,t}$, and $K_{f,t}$ denote logarithmic changes of the real exchange rate, export and foreign income, respectively. μ is the inclusion of an intercept without time trends, while refers to an intercept with time trend at this juncture for unit root tests. The critical values of the KPSS (μ) and KPSS (τ) unit root tests at 5% significance level are 0.463 and 0.146, respectively with incorporating an intercept (i.e., μ) and an intercept and time trend (i.e., τ). Referring to the unit root test results, the ADF and PP tests display that all the returns under investigation are stationary.

3. ECONOMETRIC METHODOLOGY

As our first objective is to identify a most favored multivariate GARCH-in-mean model among different other specifications to generate conditional standard deviation series for the countries under concern. With this regard, the current work methodologically follows to Grier and Perry (2004) and VAR (ρ)-MGARCH–in–mean–BEKK econometric approach is jointly employed in model estimation. In addition, we exploit five widely–used criteria which are given in Lütkepohl (2005) namely, the Akaike information criterion of Akaike (1973) (hereinafter, AIC), the Schwarz Bayesian criterion (henceforth, SBC), the Hannan–Quinn criterion (henceforward, HQC), the final prediction error (hereafter, FPE), and log–likelihood (henceforth, LL) value. These criteria are used to select the optimal lag length. For checking the adequacy of the estimated models, several diagnostic and specification tests are considered.

It is evident that the application of multivariate GARCH–in-mean model of Bollerslev et al. (1988) with VAR framework of Sims (1980) has recently become one of the most empirical methods in volatility related works (Elder, 2004). As mentioned earlier, Engle and Kroner (1995) has proposed many theoretical frameworks related to multivariate GARCH–in–mean. This approach has been relatively common in exchange rate volatility and trade flows related works. A multivariate GARCH–in–mean model which is combined with p^{th} orders VAR relies on the dynamic interrelations among the set of variables. The general equation of the study is detailed as follows

$$Y_t = M + \sum_{i=1}^{p} \Gamma^{(i)} Y_{t-1} + \Psi H_t + U_t \tag{2}$$

$U_t|\Omega_{t-1} \sim N(0,H_t)$

Where, Y_t is $n\times1$ dimensional matrix of contemporenous returns, and M is $n\times1$ dimensional matrix that denotes the coeffcient of constants. $\Gamma^{(i)}$ (i=1,...,p) is $n\times n$ dimensional matrix that represents the slope coeffcients of the lagged form for dependent variables, Y_{t-1}. Ψ represents a coefficient matrix for H_t (t=1,…T) that is an asymmetric conditional BEKK variance–covariance specification. It should be noted that H_t is assumed as a diagonal in Eq. (2) and the errors are serially not correlated. In turn, U_t is stochastic error vector of the mean equation and the elements of error vector are normally distributed with all t. Ω_{t-1} is the available information set at the time t-1 and H_t is explained through the asymmetric BEKK variance–covariance specification.

In Eq. (2), the Ψ matrix of volatility parameter is also incorporated to analyze the impacts of real exchange rate risk on export growth of the economies under concern. This is because a joint estimation of volatility parameter with the coeffcients of other determinants successfully avoids the generated regressor issue that may induce biases in the coeffcients of standard errors. It may also result in inconsistent parameter estimates (Pagan, 1984).

$$\begin{bmatrix} r_t \\ x_t \\ f_t \end{bmatrix} = \begin{bmatrix} \mu_r \\ \mu_x \\ \mu_f \end{bmatrix} + \begin{bmatrix} \gamma_{11}^{(i)} & \gamma_{12}^{(i)} & \gamma_{13}^{(i)} \\ \gamma_{21}^{(i)} & \gamma_{22}^{(i)} & \gamma_{23}^{(i)} \\ \gamma_{31}^{(i)} & \gamma_{32}^{(i)} & \gamma_{33}^{(i)} \end{bmatrix} \begin{bmatrix} r_{t-i} \\ x_{t-i} \\ f_{t-i} \end{bmatrix} + \begin{bmatrix} \psi_{11} & \psi_{12} & \psi_{13} \\ \psi_{21} & \psi_{22} & \psi_{23} \\ \psi_{31} & \psi_{32} & \psi_{33} \end{bmatrix} \begin{bmatrix} h_{11,t} \\ h_{22,t} \\ h_{33,t} \end{bmatrix} + \begin{bmatrix} u_{r,t} \\ u_{x,t} \\ u_{f,t} \end{bmatrix} \tag{3}$$

Eq. (3) can be written as follows

$$\begin{cases} r_t = \mu_r + \gamma_{11}^{(i)} r_{t-i} + \gamma_{12}^{(i)} x_{t-i} + \gamma_{13}^{(i)} f_{t-i} + \psi_{11} h_{11,t} \\ \quad + \psi_{12} h_{22,t} + \psi_{13} h_{33,t} + u_{r,t} \\ x_t = \mu_x + \gamma_{21}^{(i)} r_{t-i} + \gamma_{22}^{(i)} x_{t-i} + \gamma_{23}^{(i)} f_{t-i} + \psi_{21} h_{11,t} \\ \quad + \psi_{22} h_{22,t} + \psi_{23} h_{33,t} + u_{x,t} \\ f_t = \mu_f + \gamma_{31}^{(i)} r_{t-i} + \gamma_{32}^{(i)} x_{t-i} + \gamma_{33}^{(i)} f_{t-i} + \psi_{31} h_{11,t} \\ \quad + \psi_{32} h_{22,t} + \psi_{33} h_{33,t} + u_{f,t} \end{cases} \tag{4}$$

As mentioned above, we follow the model used by Byrne et al. (2006). By employing this model originally developed by Armington (1969), we investigate the linkage between exchange rate risk and export growth. In Eq. 4, the independent variables r_t, x_t and f_t denotes the real exchange rate returns, export growth, and foreign income returns, while r_{t-i}, x_{t-i} and f_{t-i} are lagged form of them (i=1,...,n), respectively. μ_r, μ_x, and μ_f are the intercepts of the equations and $\gamma_{11}^{(i)}$, $\gamma_{12}^{(i)}$, $\gamma_{13}^{(i)}$, $\gamma_{21}^{(i)}$, $\gamma_{22}^{(i)}$, $\gamma_{23}^{(i)}$, $\gamma_{31}^{(i)}$, $\gamma_{32}^{(i)}$, $\gamma_{33}^{(i)}$ denote the slope coeffcients of the equations (i=1,...,n). Here, the parameters ψ_{12} and ψ_{13} denote the coeffcients of interest that indicate the impact of BRICS's real exchange rate risk on export growth and foreign income, respectively. Finally, $u_{r,t}$, $u_{x,t}$ and $u_{f,t}$ are given to explain the residual terms of the respective equations.

The variables in both export and import equations is the same in many studies due to asymmetry of export and import equations (Bahmani-Oskooee, 2002). Taking under consideration, the role of foreign income and domestic income in the explanation of export and import functions, we modify the above-mentioned models (Siregar and Rajan, 2004).

Indeed, this study attempts to estimate jointly the real exchange rate, export and foreign income equations employing VAR (p) –MGARCH–in–mean–BEKK econometric approach. It includes the possible asymmetric and non–diagonality in conditional BEKK variance–covariance specification. Despite the existence of many proposed model specifications, an asymmetric version of BEKK variance–covariance parameterization of Grier and Perry (2004) is used in a quadratic form to ensure for the positive definiteness as follows[2]

$$H_t = C'C + A'u_{t-1}u_{t-1}'A + B'H_{t-1}B + D'\zeta_{t-1}\zeta_{t-1}'D \tag{5}$$

Or the matrix form of the variance–covariance specification given as follows

2 The acronym BEKK stands for the scholars Yoshi Baba, Robert Engle, Dennis Kraft, and Ken Kroner

$$H_t = \begin{bmatrix} h_{r,t}^2 & h_{r,x,t} & h_{r,f,t} \\ h_{x,r,t} & h_{x,t}^2 & h_{x,f,t} \\ h_{f,r,t} & h_{f,x.t} & h_{f,t}^2 \end{bmatrix} = \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix}' \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix}$$
$$+ \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}' \begin{bmatrix} u_{t-1} \\ u_{t-1} \\ u_{t-1} \end{bmatrix} \begin{bmatrix} u_{t-1} \\ u_{t-1} \\ u_{t-1} \end{bmatrix}' \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$
$$+ \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}' \begin{bmatrix} h_{r,t-1}^2 & h_{r,x,t-1} & h_{r,f,t-1} \\ h_{x,r,t-1} & h_{x,t-1}^2 & h_{x,f,t-1} \\ h_{f,r,t-1} & h_{f,x,t-1} & h_{f,t-1}^2 \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}$$
$$+ \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix}' \begin{bmatrix} \zeta_{t-1} \\ \zeta_{t-1} \\ \zeta_{t-1} \end{bmatrix} \begin{bmatrix} \zeta_{t-1} \\ \zeta_{t-1} \\ \zeta_{t-1} \end{bmatrix}' \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \quad (6)$$

The Eq. 6 is the conditional BEKK variance–covariance specification with the component that captures possible asymmetry and non–diagonality. Besides, it considers lagged conditional variances and co-variances, H_{t-1} as well as lagged form of $u_{t-1}u_{t-1}^{'}$ and $\zeta_{t-1}\zeta_{t-1}^{'}$ for joint estimations of real exchange rate volatility on export growth. Here, the matrices A and B capture the evidence for heteroscedastic conditional variances. As suggested by Grier and Perry (2004), the term $\zeta_{t-1}\zeta_{t-1}^{'}$ accounts for potential asymmetric responses in conditional variance–covariance specification. Thus, we define ζ_r, ζ_x and ζ_f as min $\{u_r, 0\}$, min $\{u_x, 0\}$, and min $\{u_f, 0\}$, respectively. An asymmetric and unrestricted VAR (p) – MGARCH–in–mean–BEKK model is estimated by exploiting ML estimator with multivariate Student's t distribution to H_0. Here, the ML is confirmed that the asymmetric BEKK variance–covariance specification is correctly constructed.

$$Max_\theta LogL_T(\theta) = \sum_{t=1}^{T} l_t(\theta) = c - \frac{1}{2}\sum_{t=1}^{T} \ln|H_t| - \frac{1}{2}\sum_{t=1}^{T} u_t^{'}H_{t-1}^{'}u_t \quad (7)$$

This log–likelihood function is commonly optimized multivariate Gaussian distribution, and residual terms, u_t is normally distributed. Furthermore θ is a vector of parameters. In this study, we consider Student's t density. The main distinction of the Student's t density from multivariate Gaussian distribution that it has a tail parameter, υ in this study. This additional scalar parameter normally expresses the order of existence of the moments, and it is commonly assumed to be >2, thus H_t can be always expressed as a conditional variance–covariance specification. Generally, the multivariate Student's t density for the residual terms process is explained as follows

$$(u_t; H_t; v) = \frac{\Gamma\left(\frac{v+N}{2}\right)}{\Gamma\left(\frac{1}{2}\right)[\pi(v-2)]^{\frac{N}{2}}} |H_t|^{\frac{-1}{2}} \left[1 + \frac{u_t^{'}H_t^{-1}u_t}{\in -2}\right]^{\frac{-N+\in}{2}} \quad (8)$$

Where, H_t is the conditional variance–covariance equation of the residual terms, while Γ is *gamma* function. The N is the number of variables in the system. The parameters of the conditional variance–covariance specification are jointly estimated with tail (shape) parameter, υ is included in model estimations based on multivariate Student's t density.

All in all, the parameters of this study are assessed simultaneously, rather than estimating mean and standard deviation parameters separately. To determine the statistical inference in model assessment, the robust standard errors of Bollerslev and Wooldridge (1992) are considered. To conduct optimization, the numerical algorithm named the BFGS quasi–Newton method from Press et al. (2007) is employed.[3]

4. RESULTS AND DISCUSSION

Throughout this section, the empirical results from model estimation are discussed. Our main objective is to estimate the model using the relatively new single-step procedure by employing multivariate GARCH–in–mean accounting for time series properties of the series. Thus, all the variables of interest are included in a single system. The innovations from the first moment equation are incorporated simultaneously in the second moment (variance-covariance) equation to generate the conditional standard deviation. These conditional standard deviation series are included in export equation which are the first moment or conditional mean equation. Using a single-step procedure, we determine the impacts of exchange rate risk on export growth. To achieve on this objective, we have relied on the hypothesis testing of these parameters in estimated equations. Finally, we conduct the generalized impulse response function analysis for exchange rate volatility to a one unit of export growth of the respective economies under a vector autoregression process.

4.1. Estimation Results for VAR (ρ) –MGARCH–in–Mean–BEKK Model

As mentioned earlier, we exploit five widely–used criteria which are given in Lütkepohl (2005) namely Akaike information criterion of Akaike (1973) (hereinafter, AIC), the Schwarz Bayesian criterion (henceforth, SBC), the Hannan–Quinn criterion (henceforward, HQC), the final prediction error (hereafter, FPE), and log–likelihood (henceforth, LL) value. These criteria are used to select the optimal lag length in employed model, and they include a vector autoregression process in a single equation. As far as the multivariate model is concerned, the used selection criteria show a vector autoregression order of lag four for Brazil, lag three for Russia, lag six for India, lag two for China and lag three for South Africa as the most favored estimated models. To select the most preferred model, we further relied on LL values and residual diagnostic checks. In terms of selection criteria and robustness tests as well as with the distribution of the explanatory variables (exchange rate and export growth) for the available sample sizes, the maximum vector autoregression order is set to ensure sufficient degrees of freedom and to avoid numerical convergence problems.

3 BFGS is an acronym stands for Broyden–Fletcher–Goldfarb–Shanno algorithm

In addition, the model specification and estimation results are utilized in volatility transmission and impulse response analysis between the series of concern. However, the conditional mean and variance–covariance specification of the study are jointly estimated however, their results are reported in separate tables.

In Table 4, the results for estimated mean equations of real exchange rate, export growth and foreign income for the BRICS countries are reported. Here, μ_r, μ_x, and μ_f carry the positive values Brazil's real exchange rate and export growth (Panel A), Russia's export and foreign income growth (Panel B), India's all equations (Panel C), China's exchange rate (Panel D) and South Africa's export and foreign income growth (Panel E) equations and indicates the negative values for other remaining intercepts of the equations. Moreover, we consider matrices $\Gamma^{(i)}$ (i=1,2,3,4) for Brazil, $\Gamma^{(i)}$ (i=1,2,3) for Russia and South Africa, $\Gamma^{(i)}$ (i=1,2,3,4,5,6) for India, and $\Gamma^{(i)}$ (i=1,2) for China, which are used in the mean equations and captured by the parameters $\gamma^{(i)}_{k,j}$ to realize the relationship across the return and growth series of concern. While, in Panel A of Table 4, all the diagonal parameters of $\gamma^{(i)}_{k,j}$, k=j, $\gamma^{(1)}_{r,r}$, $\gamma^{(3)}_{r,r}$, $\gamma^{(4)}_{r,r}$, $\gamma^{(1)}_{x,x}$, $\gamma^{(2)}_{x,x}$, $\gamma^{(1)}_{f,f}$, $\gamma^{(3)}_{f,f}$, $\gamma^{(4)}_{f,f}$ for Brazil (Panel A), $\gamma^{(1)}_{r,r}$, $\gamma^{(2)}_{r,r}$, $\gamma^{(3)}_{r,r}$, $\gamma^{(1)}_{x,x}$, $\gamma^{(1)}_{f,f}$, for Russia (Panel B), and $\gamma^{(1)}_{r,r}$, $\gamma^{(4)}_{r,r}$, $\gamma^{(5)}_{r,r}$, $\gamma^{(1)}_{x,x}$, $\gamma^{(2)}_{x,x}$, $\gamma^{(4)}_{x,x}$, $\gamma^{(5)}_{x,x}$, $\gamma^{(1)}_{f,f}$, $\gamma^{(3)}_{f,f}$, $\gamma^{(4)}_{f,f}$, $\gamma^{(5)}_{f,f}$ for India (Panel C) are statistically significant, just like that the diagonal parameters $\gamma^{(1)}_{r,r}$, $\gamma^{(2)}_{r,r}$, $\gamma^{(2)}_{r,r}$, $\gamma^{(2)}_{x,x}$, $\gamma^{(1)}_{f,f}$, $\gamma^{(2)}_{f,f}$ for China (Panel D) and $\gamma^{(1)}_{r,r}$, $\gamma^{(3)}_{r,r}$, $\gamma^{(1)}_{x,x}$, $\gamma^{(2)}_{x,x}$, ${}^{3}{}^{(1)}_{f,f}$, $\gamma^{(2)}_{f,f}$ for South Africa (Panel E), are statistically significant. These equations depend on their first order lag and up to four lag for Brazil, up to three lag for Russia, up to six lag for India, likewise up to two lag for China, and up to three lag for South Africa, respectively. It should be noted that the cross variable logarithmic change links between the variables under concern and it can be examined by off-diagonal elements, and the results are noteworthy.

First, the off-diagonal parameters $\gamma^{(1)}_{r,x}$, $\gamma^{(1)}_{r,f}$, $\gamma^{(4)}_{x,f}$, $\gamma^{(1)}_{f,r}$ $\gamma^{(3)}_{f,x}$, $\gamma^{(4)}_{f,x}$ for Brazil (Panel A), $\gamma^{(1)}_{r,x}$, $\gamma^{(1)}_{r,f}$, $\gamma^{(2)}_{r,f}$, $\gamma^{(3)}_{r,x}$, $\gamma^{(3)}_{r,f}$, $\gamma^{(1)}_{x,f}$, $\gamma^{(3)}_{x,r}$, $\gamma^{(2)}_{f,r}$ for Russia (Panel B), and $\gamma^{(1)}_{r,x}$, $\gamma^{(2)}_{r,f}$, $\gamma^{(3)}_{r,x}$, $\gamma^{(3)}_{r,f}$, $\gamma^{(4)}_{r,f}$ $\gamma^{(6)}_{r,x}$, $\gamma^{(2)}_{x,f}$, $\gamma^{(5)}_{x,r}$, $\gamma^{(1)}_{f,r}$, $\gamma^{(2)}_{f,r}$, $\gamma^{(3)}_{f,r}$, $\gamma^{(5)}_{f,r}$ for India (Panel C), $\gamma^{(1)}_{x,r}$, $\gamma^{(1)}_{x,f}$, $\gamma^{(2)}_{x,r}$, $\gamma^{(1)}_{f,r}$, $\gamma^{(1)}_{f,x}$, $\gamma^{(2)}_{f,r}$, $\gamma^{(2)}_{f,x}$, for China (Panel D) are statistically significant. As such, the off-diagonal parameters $\gamma^{(1)}_{r,f}$, $\gamma^{(2)}_{r,f}$, $\gamma^{(3)}_{r,f}$, $\gamma^{(1)}_{x,r}$, $\gamma^{(2)}_{x,f}$, $\gamma^{(3)}_{x,r}$, $\gamma^{(3)}_{x,f}$ for South Africa (Panel E) is statistically significant. Supplementary, their counterparts $\gamma^{(3)}_{r,f}$, $\gamma^{(4)}_{r,x}$, $\gamma^{(4)}_{r,f}$, $\gamma^{(1)}_{x,r}$, $\gamma^{(1)}_{x,f}$, $\gamma^{(2)}_{x,r}$, $\gamma^{(2)}_{x,f}$, $\gamma^{(3)}_{x,r}$, $\gamma^{(3)}_{x,x}$, $\gamma^{(3)}_{x,f}$, $\gamma^{(4)}_{x,r}$, $\gamma^{(4)}_{x,x}$ for Brazil, $\gamma^{(1)}_{x,r}$, $\gamma^{(2)}_{x,r}$, $\gamma^{(2)}_{x,f}$, $\gamma^{(2)}_{x,x}$, $\gamma^{(3)}_{x,x}$, $\gamma^{(3)}_{x,f}$, $\gamma^{(1)}_{f,r}$, $\gamma^{(1)}_{f,x}$, $\gamma^{(2)}_{f,x}$, $\gamma^{(3)}_{f,r}$, $\gamma^{(3)}_{f,x}$, $\gamma^{(3)}_{f,f}$ for Russia, and $\gamma^{(1)}_{r,f}$, $\gamma^{(2)}_{r,r}$, $\gamma^{(2)}_{r,x}$, $\gamma^{(3)}_{r,r}$, $\gamma^{(4)}_{r,x}$, $\gamma^{(5)}_{r,x}$, $\gamma^{(5)}_{r,f}$, $\gamma^{(6)}_{r,r}$, $\gamma^{(6)}_{r,f}$, $\gamma^{(1)}_{x,r}$, $\gamma^{(1)}_{x,f}$, $\gamma^{(2)}_{x,r}$, $\gamma^{(3)}_{x,r}$, $\gamma^{(3)}_{x,x}$, $\gamma^{(3)}_{x,f}$, $\gamma^{(4)}_{x,r}$, $\gamma^{(4)}_{x,f}$, $\gamma^{(5)}_{x,f}$, $\gamma^{(6)}_{x,r}$, $\gamma^{(6)}_{x,x}$, $\gamma^{(6)}_{x,f}$, $\gamma^{(1)}_{f,x}$, $\gamma^{(2)}_{f,x}$, $\gamma^{(3)}_{f,x}$, $\gamma^{(4)}_{f,r}$, $\gamma^{(4)}_{f,x}$, $\gamma^{(5)}_{f,x}$, $\gamma^{(6)}_{f,r}$, $\gamma^{(6)}_{f,x}$, $\gamma^{(6)}_{f,f}$ for India are statistically insignificant.

Table 4: Parameter estimates for VAR (p)-MGARCH-in-mean-BEKK model

Panel A: Brazil

r_t		x_t		f_t	
μ_r	1.6467***	μ_x	1.0859	μ_f	−1.6294
$\gamma^{(1)}_{r,r}$	0.3406***	$\gamma^{(1)}_{x,r}$	0.1199	$\gamma^{(1)}_{f,r}$	0.1078**
$\gamma^{(1)}_{r,x}$	−0.0183**	$\gamma^{(1)}_{x,x}$	−0.5253***	$\gamma^{(1)}_{f,x}$	−0.0073
$\gamma^{(1)}_{r,f}$	0.0041*	$\gamma^{(1)}_{x,f}$	−0.1289	$\gamma^{(1)}_{f,f}$	−0.3835***
$\gamma^{(2)}_{r,r}$	−0.0637	$\gamma^{(2)}_{x,r}$	−0.0287	$\gamma^{(2)}_{f,r}$	−0.0011
$\gamma^{(2)}_{r,x}$	−0.0143	$\gamma^{(2)}_{x,x}$	−0.2361***	$\gamma^{(2)}_{f,x}$	−0.0056
$\gamma^{(2)}_{r,f}$	−0.0350	$\gamma^{(2)}_{x,f}$	−0.0754	$\gamma^{(2)}_{f,f}$	−0.0149
$\gamma^{(3)}_{r,r}$	0.0636***	$\gamma^{(3)}_{x,r}$	0.0304	$\gamma^{(3)}_{f,r}$	0.0414
$\gamma^{(3)}_{r,x}$	−0.0179	$\gamma^{(3)}_{x,x}$	0.0353	$\gamma^{(3)}_{f,x}$	0.0488**
$\gamma^{(3)}_{r,f}$	−0.0209	$\gamma^{(3)}_{x,f}$	0.1080	$\gamma^{(3)}_{f,f}$	0.1515**
$\gamma^{(4)}_{r,r}$	0.0498**	$\gamma^{(4)}_{x,r}$	0.0070	$\gamma^{(4)}_{f,r}$	0.0264
$\gamma^{(4)}_{r,x}$	−0.0121	$\gamma^{(4)}_{x,x}$	−0.0058	$\gamma^{(4)}_{f,x}$	0.0428***
$\gamma^{(4)}_{r,f}$	−0.0032	$\gamma^{(4)}_{x,f}$	−0.1842***	$\gamma^{(4)}_{f,f}$	−0.0598*
$\Psi_{r,r}$	0.0357	$\Psi_{x,r}$	−0.1324	$\Psi_{f,r}$	−0.0206
$\Psi_{r,x}$	−0.1391**	$\Psi_{x,x}$	0.0127	$\Psi_{f,x}$	0.0526
$\Psi_{r,f}$	−0.1365*	$\Psi_{x,f}$	0.0581	$\Psi_{f,f}$	0.4963*
Shape	4.8408***	AIC	16.883	HQC	17.258
LL	−2712.0	SBC	17.825	FPE	16.893
$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'\zeta_{t-1}\zeta'_{t-1}D$					
$c_{1,1}$	1.7720***	$c_{1,2}$	—	$c_{1,3}$	—
$c_{2,1}$	0.8459	$c_{2,2}$	6.5690***	$c_{2,3}$	—
$c_{3,1}$	−0.0205	$c_{3,2}$	0.7143	$c_{3,3}$	1.8138***
$a_{1,1}$	1.1656***	$a_{1,2}$	0.1581	$a_{1,3}$	0.0605
$a_{2,1}$	0.0299	$a_{2,2}$	−0.5374***	$a_{2,3}$	−0.0802
$a_{3,1}$	−0.0448	$a_{3,2}$	0.4360	$a_{3,3}$	0.2906**
$b_{1,1}$	−0.0040	$b_{1,2}$	−0.0326	$b_{1,3}$	−0.0603
$b_{2,1}$	0.0396	$b_{2,2}$	0.2356	$b_{2,3}$	0.0695
$b_{3,1}$	0.0471	$b_{3,2}$	−0.3313	$b_{3,3}$	0.3701**
$d_{1,1}$	0.0320	$d_{1,2}$	0.4326	$d_{1,3}$	0.2041*
$d_{2,1}$	−0.0176	$d_{2,2}$	0.2332	$d_{2,3}$	−0.1258
$d_{3,1}$	−0.0712	$d_{3,2}$	0.3657	$d_{3,3}$	0.9328

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively. AIC, SBC, HQC and FPE are acronyms for the Akaike information criterion, Schwarz Bayesian criterion, Hannan-Quinn criterion and Final prediction errors, respectively, and LL stands for log-likelihood value

Likewise, the off-diagonal parameters $\gamma^{(1)}_{r,x}$, $\gamma^{(1)}_{r,f}$, $\gamma^{(2)}_{r,x}$, $\gamma^{(2)}_{r,f}$, $\gamma^{(2)}_{x,f}$ for China and $\gamma^{(1)}_{r,x}$, $\gamma^{(2)}_{r,r}$, $\gamma^{(2)}_{r,x}$, $\gamma^{(3)}_{r,x}$, $\gamma^{(1)}_{x,f}$, $\gamma^{(2)}_{x,r}$, $\gamma^{(3)}_{x,x}$, $\gamma^{(1)}_{f,r}$, $\gamma^{(1)}_{f,x}$, $\gamma^{(2)}_{f,r}$, $\gamma^{(2)}_{f,x}$, $\gamma^{(3)}_{f,r}$, $\gamma^{(3)}_{f,x}$, $\gamma^{(3)}_{f,f}$, for South Africa economies are also statistically insignificant.

As aforementioned, the main objective of this study is to examine the impacts of exchange rate risk on export growth, and it can be inferred from the sign and significance of $\Psi_{r,x}$ and $\Psi_{r,f}$ that the point estimates of these economies is equal to −0.1391 and −0.1365

Panel B: Russia

r_t		x_t		f_t	
μ_r	−0.7788	μ_x	11.218***	μ_f	0.3687
$\gamma^{(1)}_{r,r}$	0.3699***	$\gamma^{(1)}_{x,r}$	−0.2640	$\gamma^{(1)}_{f,r}$	−0.0304
$\gamma^{(1)}_{r,x}$	0.0383***	$\gamma^{(1)}_{x,x}$	−0.1962***	$\gamma^{(1)}_{f,x}$	−0.0090
$\gamma^{(1)}_{r,f}$	0.1675**	$\gamma^{(1)}_{x,f}$	−0.6684*	$\gamma^{(1)}_{f,f}$	−0.3161***
$\gamma^{(2)}_{r,r}$	−0.1962***	$\gamma^{(2)}_{x,r}$	−0.0211	$\gamma^{(2)}_{f,r}$	−0.0803**
$\gamma^{(2)}_{r,x}$	0.0027	$\gamma^{(2)}_{x,x}$	−0.0169	$\gamma^{(2)}_{f,x}$	−0.0061
$\gamma^{(2)}_{r,f}$	0.1251*	$\gamma^{(2)}_{x,f}$	0.0166	$\gamma^{(2)}_{f,f}$	−0.1111*
$\gamma^{(3)}_{r,r}$	−0.1241**	$\gamma^{(3)}_{x,r}$	−0.2441*	$\gamma^{(3)}_{f,r}$	−0.0323
$\gamma^{(3)}_{r,x}$	0.0283***	$\gamma^{(3)}_{x,x}$	0.0632	$\gamma^{(3)}_{f,x}$	0.0041
$\gamma^{(3)}_{r,f}$	0.0649*	$\gamma^{(3)}_{x,f}$	0.0925	$\gamma^{(3)}_{f,f}$	0.0795
$\Psi_{r,r}$	0.1393	$\Psi_{x,r}$	0.4332	$\Psi_{f,r}$	−0.1769**
$\Psi_{r,x}$	0.2357**	$\Psi_{x,x}$	−1.9263***	$\Psi_{f,x}$	0.1609
$\Psi_{r,f}$	−0.4365**	$\Psi_{x,f}$	1.9584*	$\Psi_{f,f}$	−0.4075
Shape	4.1181***	AIC	15.194	HQC	15.570
LL	−2084.4	SBC	16.132	FPE	15.205
$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'\zeta_{t-1}\zeta'_{t-1}D$					
$c_{1,1}$	−0.1168	$c_{1,2}$	—	$c_{1,3}$	—
$c_{2,1}$	−4.4524	$c_{2,2}$	3.8945	$c_{2,3}$	—
$c_{3,1}$	−0.5483	$c_{3,2}$	0.5757	$c_{3,3}$	−0.0024
$a_{1,1}$	0.7579***	$a_{1,2}$	0.3599**	$a_{1,3}$	−0.0149
$a_{2,1}$	0.0956***	$a_{2,2}$	−0.1664***	$a_{2,3}$	−0.0163
$a_{3,1}$	−0.1106	$a_{3,2}$	−0.0537	$a_{3,3}$	0.5385***
$b_{1,1}$	0.5381***	$b_{1,2}$	0.3812***	$b_{1,3}$	0.0109
$b_{2,1}$	0.0349**	$b_{2,2}$	0.4176***	$b_{2,3}$	−0.1606***
$b_{3,1}$	0.0506	$b_{3,2}$	0.2985	$b_{3,3}$	0.6563
$d_{1,1}$	0.6702***	$d_{1,2}$	0.8686***	$d_{1,3}$	0.0752
$d_{2,1}$	−0.1847***	$d_{2,2}$	−0.0218	$d_{2,3}$	−0.0375*
$d_{3,1}$	0.6355***	$d_{3,2}$	2.0487	$d_{3,3}$	0.7289

**, **, * indicate 1%, 5% and 10% significance level, respectively. AIC, SBC, HQC and FPE are acronyms for the Akaike information criterion, Schwarz Bayesian criterion, Hannan-Quinn criterion and final prediction errors, respectively, and LL stands for log-likelihood value

Panel C: India

r_t		x_t		f_t	
μ_r	1.0798**	μ_x	1.7161	μ_f	2.5510***
$\gamma^{(1)}_{r,r}$	0.2917***	$\gamma^{(1)}_{x,r}$	−0.3049	$\gamma^{(1)}_{f,r}$	−0.2154***
$\gamma^{(1)}_{r,x}$	−0.0268**	$\gamma^{(1)}_{x,x}$	−0.4314***	$\gamma^{(1)}_{f,x}$	−0.0239
$\gamma^{(1)}_{r,f}$	−0.0569	$\gamma^{(1)}_{x,f}$	0.2283	$\gamma^{(1)}_{f,f}$	−0.6132***
$\gamma^{(2)}_{r,r}$	−0.0251	$\gamma^{(2)}_{x,r}$	−0.1178	${}^{(2)}_{f\ r}$	−0.1925**
$\gamma^{(2)}_{r,x}$	−0.0092	$\gamma^{(2)}_{x,x}$	−0.1192***	$\gamma^{(2)}_{f,x}$	−0.0019
$\gamma^{(2)}_{r,f}$	−0.2026***	$\gamma^{(2)}_{x,f}$	0.3911**	$\gamma^{(2)}_{f,f}$	−0.2382***
$\gamma^{(3)}_{r,r}$	0.0421	$\gamma^{(3)}_{x,r}$	−0.0620	$\gamma^{(3)}_{f,r}$	−0.1416***
$\gamma^{(3)}_{r,x}$	−0.0170*	$\gamma^{(3)}_{x,x}$	0.0270	$\gamma^{(3)}_{f,x}$	0.0041
$\gamma^{(3)}_{r,f}$	−0.1713***	$\gamma^{(3)}_{x,f}$	0.1821	$\gamma^{(3)}_{f,f}$	−0.0933*
$\gamma^{(4)}_{r,r}$	−0.1101***	$\gamma^{(4)}_{x,r}$	−0.1366	$\gamma^{(4)}_{f,r}$	−0.0503
$\gamma^{(4)}_{r,x}$	−0.0110	$\gamma^{(4)}_{x,x}$	−0.1553***	$\gamma^{(4)}_{f,x}$	0.0131
$\gamma^{(4)}_{r,f}$	−0.0538*	$\gamma^{(4)}_{x,f}$	0.0754	$\gamma^{(4)}_{f,f}$	−0.0906**
$\gamma^{(5)}_{r,r}$	0.1084***	$\gamma^{(5)}_{x,r}$	−0.7790***	$\gamma^{(5)}_{f,r}$	−0.0951**
$\gamma^{(5)}_{r,x}$	0.0228	$\gamma^{(5)}_{x,x}$	−0.1658***	$\gamma^{(5)}_{f,x}$	−0.0125
$\gamma^{(5)}_{r,f}$	0.0256	$\gamma^{(5)}_{x,f}$	0.2352	$\gamma^{(5)}_{f,f}$	−0.0859*
$\gamma^{(6)}_{r,r}$	0.0225	$\gamma^{(6)}_{x,r}$	0.1355	$\gamma^{(6)}_{f,r}$	−0.0417
$\gamma^{(6)}_{r,x}$	0.0252**	$\gamma^{(6)}_{x,x}$	0.0226	$\gamma^{(6)}_{f,x}$	−0.0102
$\gamma^{(6)}_{r,f}$	0.0120	$\gamma^{(6)}_{x,f}$	0.1985	$\gamma^{(6)}_{f,f}$	0.0128
$\Psi_{r,r}$	0.0358	$\Psi_{x,r}$	0.8347**	Ψ_{fr}	0.8722***
$\Psi_{r,x}$	−0.3329***	$\Psi_{x,x}$	−0.0883	Ψ_{fx}	−0.2873**
$\Psi_{r,f}$	0.3621***	$\Psi_{x,f}$	−0.7873**	$\Psi_{f,f}$	−0.6074**
Shape	4.3362***	AIC	14.341	HQC	14.801
LL	−2259.0	SBC	15.494	FPE	14.361
$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'\zeta_{t-1}\zeta'_{t-1}D$					
$c_{1,1}$	0.2825**	$c_{1,2}$	—	$c_{1,3}$	—
$c_{2,1}$	3.7325***	$c_{2,2}$	−2.9280***	$c_{2,3}$	—
$c_{3,1}$	−0.4194**	$c_{3,2}$	−0.9497***	$c_{3,3}$	0.1995
$a_{1,1}$	0.9672***	$a_{1,2}$	−1.6646***	$a_{1,3}$	−0.5749***
$a_{2,1}$	−0.0118	$a_{2,2}$	0.0028	$a_{2,3}$	0.0337
$a_{3,1}$	−0.0824	$a_{3,2}$	−0.5538***	$a_{3,3}$	0.6797***
$b_{1,1}$	0.2636*	$b_{1,2}$	0.3425	$b_{1,3}$	0.3421***
$b_{2,1}$	−0.1108***	$b_{2,2}$	0.3432***	$b_{2,3}$	−0.0920***
$b_{3,1}$	−0.1185*	$b_{3,2}$	0.1163	$b_{3,3}$	0.3867
$d_{1,1}$	−0.6597**	$d_{1,2}$	0.1610	$d_{1,3}$	0.7199**
$d_{2,1}$	0.0494	$d_{2,2}$	0.4054***	$d_{2,3}$	0.05109
$d_{3,1}$	0.2809**	$d_{3,2}$	1.6519***	$d_{3,3}$	0.2393

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively. AIC, SBC, HQC and FPE are acronyms for the Akaike information criterion, Schwarz Bayesian criterion, Hannan-Quinn criterion and Final prediction errors, respectively, and LL stands for log-likelihood value

in Brazil (Panel A), 0.2357 and −0.4365 in Russia(Panel B), respectively. Moreover, −0.3329 and 0.3621 in India (Panel C), −1.5483 and 0.0406 in China (Panel D), and −0.3285 and 5.9129 in South Africa (Panel E), respectively. As a result, relying on model estimation, the conditional standard deviation of Brazil, India, China and South Africa's exchange rate volatility has a significant negative impacts on export growth of the economy. However, the exchange rate risk has significant positive impact on its export growth in Russia. Additionally, the tail parameters (i.e., shape) of all models show that these results are statistically significant.

Panels A,B,C,D,E in Table 4, further inform the estimated parameters of matrices C,A,B, and D which are detailed in the conditional second moment equation. In the equation, the diagonal elements of matrix A, $a_{1,1}$, $a_{2,2}$, $a_{3,3}$ capture own ARCH effects, while the off-diagonal elements $a_{1,2}$, $a_{2,1}$, $a_{1,3}$, $a_{3,1}$, $a_{2,3}$, and $a_{3,2}$ evaluate the effects of shock to real exchange rate lagged return on the contemporaneous export and foreign income growth of the economies under concern. Referring on the table entries, a set of results are worth mentioning. Firstly, the statistical significant coefficient of $a_{1,1}$, $a_{2,2}$, and $a_{3,3}$ for Brazil, Russia and China economies imply that the volatilities of exchange rate returns and

Panel D: China

r,t		x_t		f_t	
μ_r	0.4097***	μ_x	−11.571***	μ_f	−7.5774***
$\gamma^{(1)}_{r,r}$	0.3827***	$\gamma^{(1)}_{x,r}$	−0.6479***	$\gamma^{(1)}_{f,r}$	−0.3039***
$\gamma^{(1)}_{r,x}$	0.0015	$\gamma^{(1)}_{x,x}$	−0.3735***	$\gamma^{(1)}_{f,x}$	0.0398***
$\gamma^{(1)}_{r,f}$	0.0157	$\gamma^{(1)}_{x,f}$	0.2330***	$\gamma^{(1)}_{f,f}$	−0.2858***
$\gamma^{(2)}_{r,r}$	−0.0316**	$\gamma^{(2)}_{x,r}$	0.1181**	$\gamma^{(2)}_{f,r}$	0.1031***
$\gamma^{(2)}_{r,x}$	0.0056	$\gamma^{(2)}_{x,x}$	−0.1016***	$\gamma^{(2)}_{f,x}$	0.0320***
$\gamma^{(2)}_{r,f}$	−0.0158	$\gamma^{(2)}_{x,f}$	0.0137	$\gamma^{(2)}_{f,f}$	−0.1098***
$\Psi_{r,r}$	6.6036***	$\Psi_{x,r}$	−95.005***	$\Psi_{f,r}$	−41.168***
$\Psi_{r,x}$	−1.5483***	$\Psi_{x,x}$	23.357***	$\Psi_{f,x}$	10.379***
$\Psi_{r,f}$	0.0406***	$\Psi_{x,f}$	0.0489	$\Psi_{f,f}$	−0.0410*
Shape	3.1169***	AIC	13.704	HQC	13.995
LL	−2217.6	SBC	14.435	FPE	13.708
$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'\zeta_{t-1}\zeta'_{t-1}D$					
$c_{1,1}$	1.3833***	$c_{1,2}$	—	$c_{1,3}$	—
$c_{2,1}$	−2.6254***	$c_{2,2}$	3.9229***	$c_{2,3}$	—
$c_{3,1}$	−0.1894***	$c_{3,2}$	−0.1540	$c_{3,3}$	−0.3158*
$a_{1,1}$	−0.0306***	$a_{1,2}$	−0.3320***	$a_{1,3}$	0.1687***
$a_{2,1}$	−0.0291***	$a_{2,2}$	−0.0339***	$a_{2,3}$	0.3572***
$a_{3,1}$	0.0033**	$a_{3,2}$	0.0048	$a_{3,3}$	1.2581***
$b_{1,1}$	−0.3020***	$b_{1,2}$	−2.3846***	$b_{1,3}$	−0.0817
$b_{2,1}$	0.0360***	$b_{2,2}$	0.3912***	$b_{2,3}$	0.0123
$b_{3,1}$	−0.0120***	$b_{3,2}$	−0.0512***	$b_{3,3}$	0.0004
$d_{1,1}$	−0.2828***	$d_{1,2}$	−1.0846***	$d_{1,3}$	0.4696***
$d_{2,1}$	0.0495***	$d_{2,2}$	0.2429***	$d_{2,3}$	−0.0311
$d_{3,1}$	−0.0049	$d_{3,2}$	0.0822***	$d_{3,3}$	0.5966***

Notes: The asterisk ***, **, *indicate 1%, 5% and 10% significance level, respectively. AIC, SBC, HQC and FPE are acronyms for the Akaike information criterion, Schwarz Bayesian criterion, Hannan-Quinn criterion and final prediction errors, respectively, and LL stands for log-likelihood value.

Panel E: South Africa

r_t		x_t		f_t	
μ_r	−9.1905***	μ_x	8.1185***	μ_f	38.872***
$\gamma^{(1)}_{r,r}$	0.1906***	$\gamma^{(1)}_{x,r}$	0.4506***	$\gamma^{(1)}_{f,r}$	−0.0449
$\gamma^{(1)}_{r,x}$	−0.0079	$\gamma^{(1)}_{x,x}$	−0.6413***	$\gamma^{(1)}_{f,x}$	−0.0107
$\gamma^{(1)}_{r,f}$	−0.0495**	$\gamma^{(1)}_{x,f}$	0.2613	$\gamma^{(1)}_{f,f}$	−0.5870***
$\gamma^{(2)}_{r,r}$	−0.0571	$\gamma^{(2)}_{x,r}$	0.0173	$\gamma^{(2)}_{f,r}$	−0.0049
$\gamma^{(2)}_{r,x}$	0.0021	$\gamma^{(2)}_{x,x}$	−0.2806***	$\gamma^{(2)}_{f,x}$	−0.0108
$\gamma^{(2)}_{r,f}$	−0.0844**	$\gamma^{(2)}_{x,f}$	0.6310***	$\gamma^{(2)}_{f,f}$	−0.2327***
$\gamma^{(3)}_{r,r}$	0.1441***	$\gamma^{(3)}_{x,r}$	0.3294***	$\gamma^{(3)}_{f,r}$	−0.0081
$\gamma^{(3)}_{r,x}$	−0.0067	$\gamma^{(3)}_{x,x}$	0.0291	$\gamma^{(3)}_{f,x}$	−0.0154
$\gamma^{(3)}_{r,f}$	−0.0658**	$\gamma^{(3)}_{x,f}$	0.2656**	$\gamma^{(3)}_{f,f}$	0.0558
$\Psi_{r,r}$	0.1337**	$\Psi_{x,r}$	0.3874***	$\Psi_{f,r}$	0.6814***
$\Psi_{r,x}$	−0.3285**	$\Psi_{x,x}$	0.2860***	$\Psi_{f,x}$	1.7685***
$\Psi_{r,f}$	5.9129***	$\Psi_{x,f}$	−5.2681***	$\Psi_{f,f}$	−28.310***
Shape	3.7682	AIC	15.898	HQC	16.232
LL	−2566.0	SBC	16.735	FPE	15.905
$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'\zeta_{t-1}\zeta'_{t-1}D$					
$c_{1,1}$	0.1898	$c_{1,2}$	—	$c_{1,3}$	—
$c_{2,1}$	3.3259***	$c_{2,2}$	2.1203***	$c_{2,3}$	—
$c_{3,1}$	0.8629***	$c_{3,2}$	0.6418***	$c_{3,3}$	0.0420
$a_{1,1}$	−0.0630	$a_{1,2}$	−0.6804***	$a_{1,3}$	−0.0771***
$a_{2,1}$	−0.0203*	$a_{2,2}$	0.1242**	$a_{2,3}$	0.0052
$a_{3,1}$	0.0581	$a_{3,2}$	−1.7513***	$a_{3,3}$	−0.1935***
$b_{1,1}$	0.9117***	$b_{1,2}$	−0.1388***	$b_{1,3}$	0.0034
$b_{2,1}$	0.0063	$b_{2,2}$	0.8323***	$b_{2,3}$	−0.0119***
$b_{3,1}$	−0.0651	$b_{3,2}$	−1.0202***	$b_{3,3}$	0.8288***
$d_{1,1}$	0.5340***	$d_{1,2}$	0.9235***	$d_{1,3}$	−0.1146***
$d_{2,1}$	0.0392***	$d_{2,2}$	−0.1624**	$d_{2,3}$	0.0299***
$d_{3,1}$	0.0357	$d_{3,2}$	−0.8807***	$d_{3,3}$	−0.0007

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively. AIC, SBC, HQC and FPE are acronyms for the Akaike information criterion, Schwarz Bayesian criterion, Hannan-Quinn criterion and final prediction errors, respectively and LL stands for log-likelihood value

export growth of these economies are affected by the shocks from their own returns, respectively. Secondly, we found an evidence of bi-directional shock transmissions between the volatility of exchange rates, export and foreign income growth of India and South Africa's economies. Because, the off-diagonal parameters $a_{1,2}$, $a_{2,1}$, $a_{1,3}$, $a_{3,1}$, $a_{2,3}$ and $a_{3,2}$ are statistically significant for China's economy. Likewise, both parameters $a_{1,2}$, $a_{2,1}$, for Russia, $a_{1,2}$, $a_{1,3}$, $a_{3,1}$, $a_{3,2}$ for India and $a_{1,2}$, $a_{2,1}$, $a_{1,3}$, $a_{3,2}$ are statistically significant for South Africa conomies, respectively. Moreover, the all off-diagonal parameters for Brazil, $a_{1,3}$, $a_{3,1}$, and $a_{2,3}$, $a_{3,2}$ for Russia, $a_{2,1}$, $a_{3,1}$, $a_{2,3}$, for India, $a_{3,1}$, $a_{2,3}$, for South Africa are statistically insignificant.

Similar to the interpretation of the elements of matrix *A,* the diagonal elements, $b_{1,1}$, $b_{2,2}$ and $b_{3,3}$ in matrix *B*, capture own GARCH effects, while off-diagonal elements, $b_{1,2}$, $b_{2,1}$, $b_{3,1}$, $b_{2,3}$ and $b_{3,2}$ measure the effects of lagged volatility of exchange rate on export and foreign income growth for the respective economies under concern. Since the diagonal elements of the matrix *B*, $b_{1,1}$, $b_{2,2}$ and $b_{3,3}$ generally express a strong GARCH(1,1) process which drives from the conditional standard deviations, all these statistical elements (except for the exchange rate returns and export growth of Brazil and for the foreign income growth of Russia, India and China economies) for the respective economies showing the highly heteroscedasticity in residual terms of the employed model. Moreover, we found the bi-directional adverse volatility spillover effect from the real exchange rate volatility to export and foreign income growth of Russia, India, China and South Africa economies, but uni-directional volatility spillover effect from exchange rate volatility to export and foreign income growth of Brazil economy. Indeed, this is due to fact that the point estimate of $b_{2,1}$, $b_{1,2}$, $b_{2,3}$ for Russia, $b_{2,1}$, $b_{2,3}$, $b_{1,3}$, $b_{3,1}$ for India, and $b_{2,1}$, $b_{1,2}$, $b_{3,1}$, $b_{3,2}$ for China, $b_{1,2}$, $b_{2,3}$, $b_{3,2}$ for South Africa economies are statistically significant. However, all off-diagonal elements for Brazil economy and that of $b_{1,3}$, $b_{3,1}$, $b_{3,2}$ of Russia, $b_{1,2}$, $b_{3,2}$ for India, $b_{1,3}$, $b_{2,3}$ for China, $b_{2,1}$, $b_{1,3}$, $b_{3,1}$ for South Africa economies are statistically insignificant. It should be noted that the volatility of real exchange rates does have an impact on the current instability of export growth of Russia, India, China and South Africa's economies. However, the exchange rate volatility does not have an impact on the current instability of export growth of Brazil.

In addition, as far as asymmetric parameter matrix *D* is concerned, there is evidence of an asymmetric response to positive shocks for returns, as a diagonal parameters $d_{1,1}$, $d_{2,2}$, and $d_{3,3}$ are statistically significant of the respective economies (except Brazil and Russia economies). Based on model assessment, the significance of $d_{1,1}$, $d_{2,2}$ and $d_{3,3}$ implies that real exchange rate volatility and export growth display their own variance asymmetry to positive shocks. Therefore, a positive growth shock leads to more volatility on growth series, but negative shock of a similar magnitude does not. The statistically significant off-diagonal elements of the matrix D, specially $d_{1,3}$ for Brazil, $d_{1,2}$, $d_{2,1}$, $d_{2,3}$ $d_{3,1}$ for Russia, $d_{1,3}$, $d_{3,1,}$ $d_{3,2}$ for India and $d_{1,2}$, $d_{1,3}$, $d_{2,1}$, $d_{3,2}$ for China, $d_{1,2}$, $d_{1,3,}$ $d_{2,1}$, $d_{2,3,}$ $d_{3,2}$ and for South Africa, respectively. All in all, the real exchange rate volatility of them responses asymmetrically towards to the shocks of export growth of the respective economies under concern.

4.2. Robustness Checks and Model Specification

Since the specified first and second moment equations are estimated by using quasi–maximum likelihood estimation, proposed by Bollerslev and Wooldridge (1992) as a way to inspect the robustness of the model, we performed serial dependence and heteroscedasticity tests relying on the standardized residuals of exchange rate export and foreign income growth equations. These standardized residuals are defined as $z_{j,t} = u_{j,t} / \sqrt{h_{j,t}}$ for j=r,x and f, where, they represent the returns of real exchange rate and export, foreign income growths. The entries of Table 5 present the results for robustness checks: Univariate and multivariate tests for the standardized residuals of real exchange rate ($z_{r,t}$), export ($z_{x,t}$) and foreign income ($z_{f,t}$) growth equations for the respective economies. Table 5 reports the Ljung–Box Q test of Ljung and Box (1978) and the McLeod–Li test of McLeod and Li (1983) statistics which refer to serial correlation and dependence in univariate versions of the standardized residuals at lag eight for all economies under concern, respectively. The ARCH Langrage multiplier (hereinafter, LM) test shows the remaining heteroscedasticity up to lag eight with statistically significant p–values (except for the standardized residuals of the export and foreign income growths equations ($z_{x,t}$) and ($z_{f,t}$) for India and the export growth equation ($z_{x,t}$) for South Africa. In turn, the multivariate version of the serial correlation and the ARCH test for heteroscedasticity have been applied to the vector of series as a whole. Additionally, the table entries have an asymptotic Chi–square (χ^2) distribution with a degree of freedom equal to the number of restricted parameters.

Table 5 further presents multivariate version of the serial dependence test by Hosking (1980). To test for the remaining heteroscedasticity in standardized residuals, the ARCH LM test of Engle (1982) is utilized and a multivariate test routine is proposed by the RATS software packages.

All in all, the heteroscedasticity test results suggest that there is no remaining heteroscedasticity in standard errors, and the conditional mean and variance–covariance specifications of the study are found as well–specified. Following to Grier and Perry (2004), we also conducted the specification tests for the adequacy of model estimation. The tests statistics with null hypotheses are reported in Table 6 and they are noteworthy. First, relying on preliminary data analysis, there is significant conditional heteroscedasticity in the series of concern.

It can be also confirmed that the parameter matrices A, B and D provide the jointly statistically significant parameter estimates. As given in Table 6, all the entries of the elements of parameter matrices are jointly significant, and express well–specified second moment equation. Second, the jointly statistical significant off–diagonal elements of these parameter matrices express that the lagged conditional variances in real exchange rate volatility of the respective economies have an impact on export growth. Next, the joint significance of the elements of parameter matrix D clarifies that the specified conditional second moment equation is asymmetric.

As stated, the asymmetric responses are detected for the specified model on the linkage between real exchange rate volatility and export growth of the BRICS economies. Moreover, the significance of $a_{1,1}$ and $d_{1,1}$ shows evidence of variance asymmetry in real exchange rate, and it expresses that the negative innovations in real exchange rate return for the respective economies lead to more real exchange rate volatility than positive shocks. Likewise, the significance of $a_{2,2}$, $d_{2,2}$, $a_{3,3}$, and $d_{3,3}$ also displays the response of own variance asymmetry in export and foreign income growth,

Table 5: Robustness checks

Country	Univariate	$z_{r,t}$	$z_{x,t}$	$z_{f,t}$	Multivariate	Statistic
Brazil	Ljung-Box Q (8)	9.6065	4.9323	9.1909	Multivariate Q (8)	68.168
	Mc-Leod-Li (8)	1.4321	3.3039	4.7136		
	ARCH LM (8)	0.2340	0.3750	0.3960		
Russia	Ljung-Box Q (8)	9.6008	10.756	5.9847	Multivariate Q (8)	79.526
	Mc-Leod-Li (8)	0.2927	3.2050	2.2395		
	ARCH LM (8)	0.0330	0.3280	0.2430		
India	Ljung-Box Q (8)	4.0112	3.4095	3.8400	Multivariate Q (8)	46.661
	Mc-Leod-Li (8)	3.3690	23.340	16.730		
	ARCH LM (8)	0.3790	3.6010***	2.5320***		
China	Ljung-Box Q (8)	3.2981	4.2825	6.8416	Multivariate Q (8)	118.83
	Mc-Leod-Li (8)	0.0330	2.4080	7.4022		
	ARCH LM (8)	0.0040	0.2740	0.8340		
South Africa	Ljung-Box Q (8)	5.2359	2.9660	6.8108	Multivariate Q (8)	35.151
	Mc-Leod-Li (8)	4.4980	28.399***	2.2006		
	ARCH LM (8)	0.4920	3.2370***	0.2450		

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively. $R_{r,t}$, $R_{x,t}$, and $R_{f,t}$ denote logarithmic changes of exchange rate returns, export and foreign income growth, respectively

Table 6: Specification tests

Brazil	Diaganal VAR	H_0: γ_{ij}=0, if $i\neq j$; i=1,2,3	χ^2 (12) = 25.898***
	Diaganal GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, if $i\neq j$; i,j=1,2,3	χ^2 (18) = 3.1313***
	No GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, for all i,j=1,2,3	χ^2 (27) = 26.205***
	No GARCH-M	H_0: Ψ_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 14.018***
	No asymmetry	H_0: d_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 9.3190***
Russia	Diaganal VAR	H_0: γ_{ij}=0, if $i\neq j$; i=1,2,3	χ^2 (9) = 25.409***
	Diaganal GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, if $i\neq j$; i,j=1,2,3	χ^2 (18) = 13.656***
	No GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, for all i,j=1,2,3	χ^2 (27) = 202.29***
	No GARCH-M	H_0: Ψ_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 5.8616***
	No asymmetry	H_0: d_{ij}=0, for all i,j=1,2,3	χ^2 (10) = 16.694***
India	Diaganal VAR	H_0: γ_{ij}=0, if $i\neq j$; i=1,2,3	χ^2 (18) = 11.959***
	Diaganal GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, if $i\neq j$; i,j=1,2,3	χ^2 (18) = 22.609***
	No GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, for all i,j=1,2,3	χ^2 (27) = 39.698***
	No GARCH-M	H_0: Ψ_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 7.0266***
	No asymmetry	H_0: d_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 6.8099***
China	Diaganal VAR	H_0: γ_{ij}=0, if $i\neq j$; i=1,2,3	χ^2 (6) = 140.53***
	Diaganal GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, if $i\neq j$; i,j=1,2,3	χ^2 (18) = 17130.7***
	No GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, for all i,j=1,2,3	χ^2 (27) = 1041.6***
	No GARCH-M	H_0: Ψ_{ij}=0, for all i,j=1,2,3	χ^2 (6) = 5411.1***
	No asymmetry	H_0: d_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 1283.7***
South Africa	Diaganal VAR	H_0: γ_{ij}=0, if $i\neq j$; i=1,2,3	χ^2 (9) = 98.403***
	Diaganal GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, if $i\neq j$; i,j=1,2,3	χ^2 (18) = 71.912***
	No GARCH	H_0: $a_{ij}=b_{ij}=d_{ij}$=0, for all i,j=1,2,3	χ^2 (27) = 4357.4***
	No GARCH-M	H_0: Ψ_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 1265.5***
	No asymmetry	H_0: d_{ij}=0, for all i,j=1,2,3	χ^2 (9) = 27.220***

The asterisk ***, **, * indicate 1%, 5% and 10% significance level, respectively

and it implies that negative export and foreign income shocks. Finally, the elements of the matrix Ψ (psi) state the existence of GARCH–M effects. All in all, the estimated models of the respective economies under investgiation are found with sound specification.

Figure 2 illustrates visual inspections that Brazil produced a strong performance in exchange rate return volatility dynamics and that the conditional standard deviation was highly volatile for the first half of 1990's, reaching the highest level in 1991 then again collapsed over time from around 50 to slightly above its original level. Also, it should be noted that Brazil's exchange rate was fluctuating significantly for the period for 1999, 2002, 2004–2005 and 2009's, respectively. The uncertainty performances of Brazil's export and foreign income growth series display exceedingly frequent fluctuations over the sample period, including the 1991, 1992 and 1997–1999 middle volatiles, and the highest volatiles are between 2008 and 2009's. After the Brazilian currency crisis in January 1999, Brazil adopted a new economic policy based on the following guides: floating exchange rate regime, inflation targeting regime and the generation of primary fiscal surpluses, that has resulted in interest rates lower than the former period (1995–1998) but still high and volatile exchange rates.

Likewise, Russia and India's economies also exhibit highly volatile performances in exchange rate returns, but their estimated standard deviations are quite low (below 50% for Russia and around 17% for India) compared to Brazil's exchange rate volatility for the whole sample period, except for during the 1999 and 2014 fiscal years in Russia and during the 1992, 1996 and 2009 fiscal years in India. Similar observations have also smarted in exchange rate volatility and export growth uncertainty performances of China and South Africa economies. Initially, China's exchange rate volatility and export growth trend gradually increased and grasped it's the highest level (around 10% for exchange rate and 40 percent for export growth) in 1994; after, sudden and sharp declines were routine, and this steady decrease is enduring at around 1.8% for exchange rate and 8% for export growth until now.

In the case of South Africa's economy, the real exchange rate volatility and export performances of its real exchange rate returns and export growth are more abnormal compared to the other BRICS countries. On the other hand, some studies provide evidence supporting a positive relationship between exchange rate volatility and trade flows. South Africa's exchange rate risk and exports growth uncertainty consequently, its impact on the economy for the sample periods, 1992–1993, 1998, 2002 and 2009's respectively.

4.3. Generalized Impulse Response Function Analysis

Hitherto, with the crucial linkages of the variables under study adequately discussed, an analytical framework of the dynamic impulse response of exchange rate volatility on one unit of export growth shocks under a vector autoregression process and vice versa will be inspected. To scrutinize the time profile of the impact of exchange rate volatility shocks on future behavior of export growth, we employed the generalized impulse response function (hereinafter, GIRF) proposed by Koop et al. (1996). We plotted an analytical framework of impulse responses of real exchange rate volatility to one unit of export growth under the vector autoregression process. Following to Grier and Perry (2004), the shock effects of real exchange rate volatility on export growth are defined through the conditional mean and with a lag through the

Figure 2: Estimated conditional variances of the growth for the sample periods

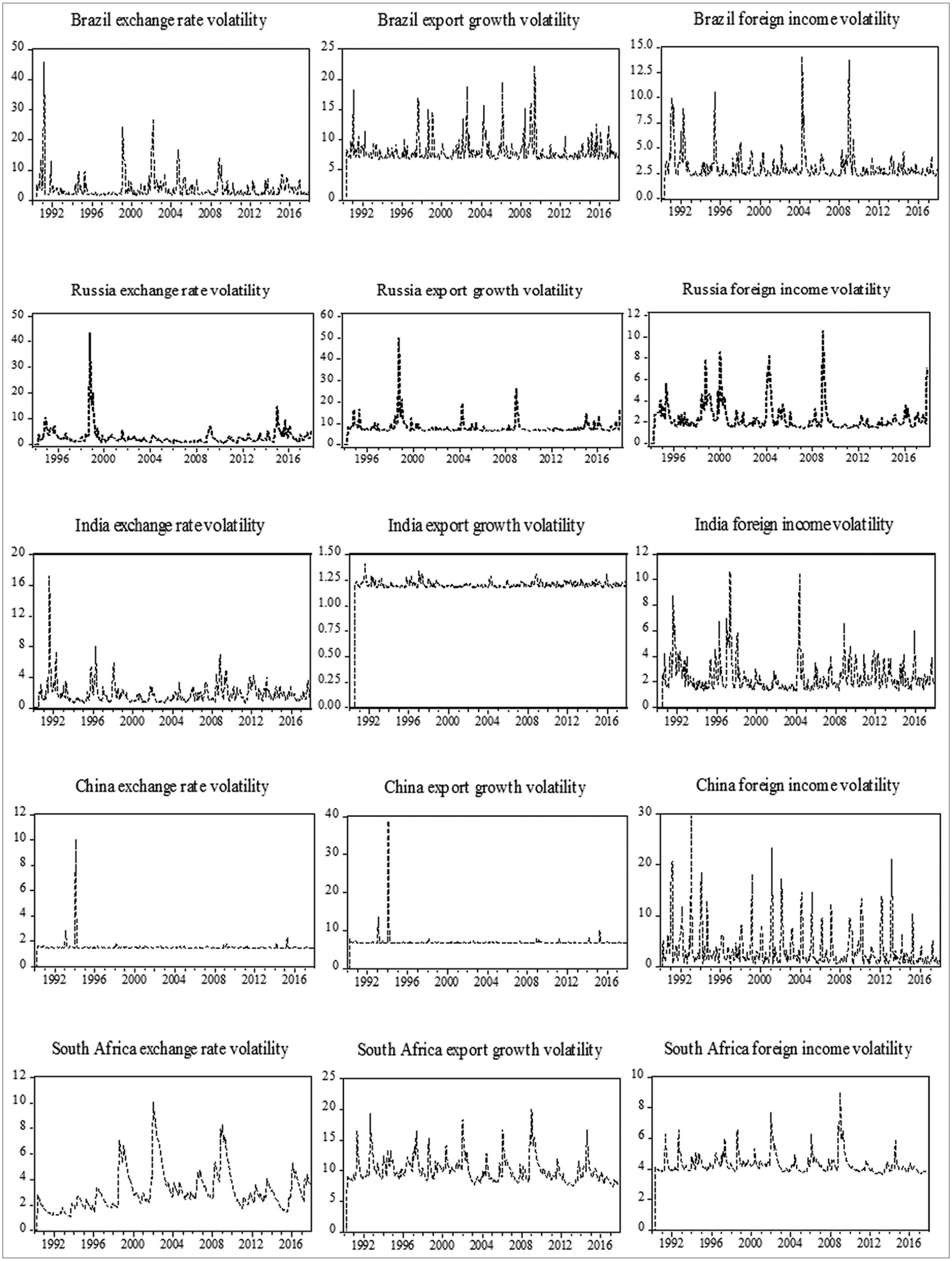
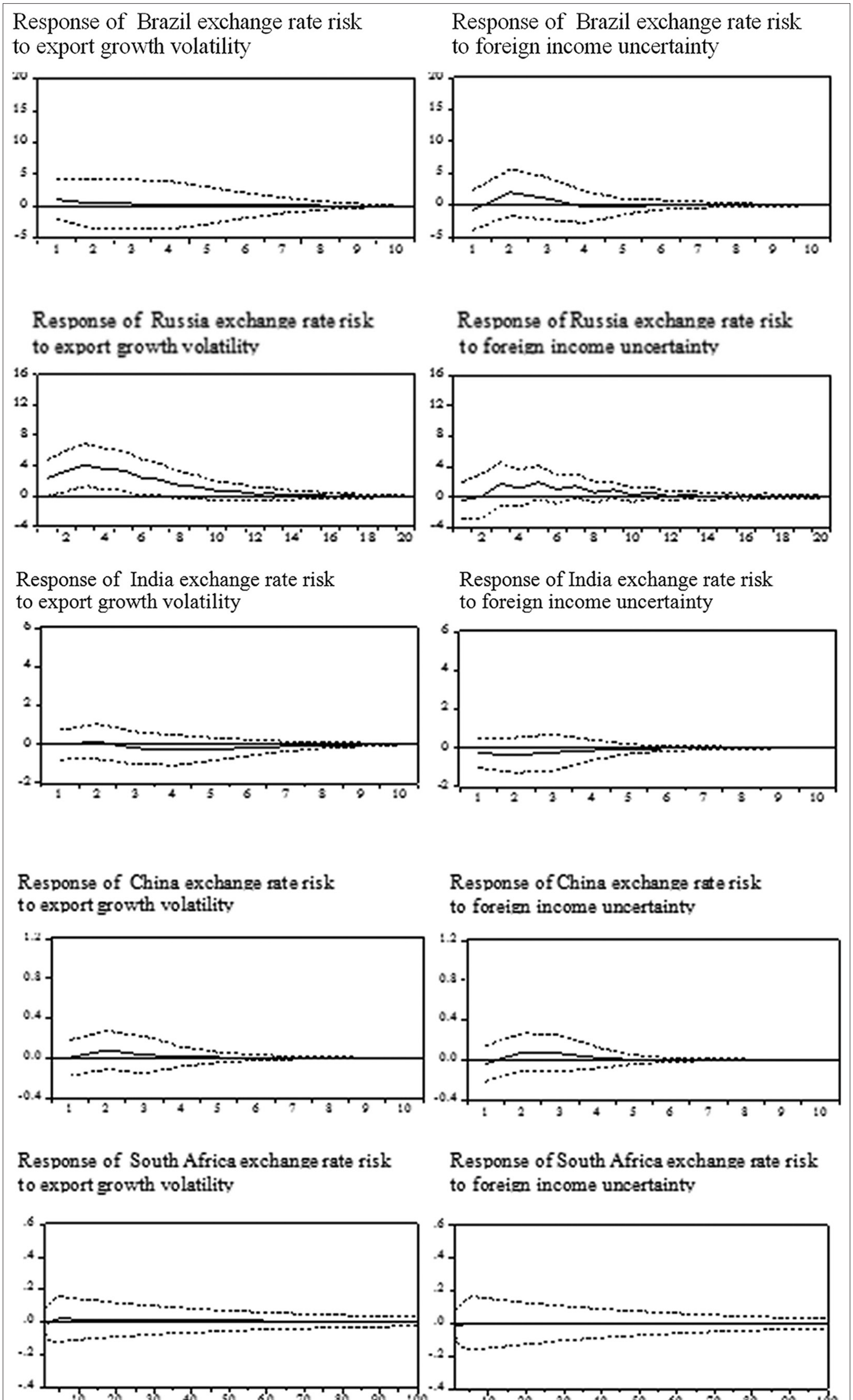


Figure 3: Generalized impulse response function of exchange rate returns under vector autoregression process to a unit (one standard deviation) shock of export volatility and foreign income uncertainty, and vice versa. Innovations 8.S.E



second moment equation. As given in Grier and Perry (2004) the GIRF of the study is detailed as follows

$$GIRF_K(n,\varrho_t,\omega_{t-1}) = \mathrm{E}[K_{t+n}|\varrho_t,\omega_{t-1}]-E[K_{t+n}|\omega_{t-1}] \quad (9)$$

Where, n=0,1,2,3..., thus the GIRF is conditional on ϱ_t and ω_{t-1} and constructs the response by averaging out future shocks given in the past and present. By giving this, a natural reference point for GIRF is the conditional expectation of K_{t+n} given only the history ω_{t-1}, and in this benchmark response the current shock is also averaged out.

The analytical framework of the GIRF of exchange rate returns to one standard deviation shocks of export volatility and foreign income uncertainty under the vector autoregression process of the respective economies under concern are illustrated in Figure 3.

Referring to Figure 3, the solid black line is the response to a unit of shock innovations, while the dashed lines are the confidence intervals; each unit time horizon denotes a month. There is evidence to suggest that the shocks of exchange rate risk have a positive and statistically significant impact on export growth volatility and foreign income uncertainty of Brazil, Russia and China economies (except India economy), while ambiguously exposing South Africa economy. Prior to the effect of the shock, the exchange rate risk of BRICS's countries have an immediate response of approximately 0.5%, 4%, −0.5%, and 0.5%, 0.2%, respectively. The GIRF grows after the shock effect in Brazil and China economies and reaches 0.5% point of the initial unit shock within fifth and six months; this effects takes around ten months for fully dissipate. Furthermore, after the shock effect in Russia and South Africa economies and reaches 4% and 0.2% point of the initial unit shock within fifteen and forty fifth months, respectively. Full recovery requires more than twenty fifth and fourscore months. In the case of India economy after the shock effect is −0.5%, and initial unit shock within seven months; full recovery requires more than ten months. Generally, the exchange rate risk of Brazil, Russia, China and South Africa economies seem to have a positive and significant impact in the response to shocks of export growth volatility and foreign income uncertainty, however, the exchange rate risk of India economy seems to have a negative impact in the response to shocks of export growth volatility and foreign income uncertainty for the same sample period.

5. CONCLUSION

This paper examines the relationship between exchange rate risk on export growth for the emerging market economies Brazil, Russia, India, China and South Africa. Besides, an analytical framework of impulse responses is conducted between the variables of interest. These frameworks involve responses of real exchange rate volatility for the respective economies after export growth shocks and is examined by using a vector autoregression process. To achieve in the specified objectives of the study, a multivariate version of an asymmetric and unrestricted econometric approach, VAR (ρ)–MGARCH–in–mean–BEKK is employed and the results are noteworthy. It should be noted that the conditional variances of Brazil, India, China and South Africa's real exchange rate have a significant negative impact on export growth of the economy, while the impact is positive in Russia. The impulse response function analysis under a vector autoregression model shows that the model incorporating uncertainty tends to exhibit the effect of shocks is more protracted. Importantly, the results of the analysis are instructive for policymakers in BRICS economies. In sum, the export growth of BRICS countries (except Russia) are prone to being effected by unfavorable exchange rate movements. Based on all of the previous arguments, these countries seem to benefit by curbing unfavorable exchange rate volatility. Indeed, factors other than the exchange rate regimes should also play a crucial role in attempts to stabilize the exchange rates.

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