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# Spillover Effects in the Up and Down Stock Market Movements: A Dynamic Conditional Correlation Model

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**Abstract**

In this paper, we have used daily stock returns data from four developed and four emerging countries to analyse the behaviour of returns and volatility spillovers in two different stock market conditions called the up and down markets. To examine this, we have proposed a VAR-MGARCH-in-mean type model and incorporated the smooth transition behaviour to switch from one market condition to another. The results show that, in general, there is significant and asymmetric effect of returns and volatility of one market on another in up and down markets but the sign of the effect varies over pairs of countries concerned and market conditions.

*Keywords:* Up-down market, risk-return relationship, DCC, MGARCH, spillover effects
*JEL:* C12, C32, C51, C52, G1

## 1. Introduction

The analysis of international financial system and the interconnection of markets have become major topics of research in financial econometrics in recent years. The availability of daily data and the likely connectedness of financial markets have inspired analysis of the transmission mechanism of different stock markets. Studying the transmission of movements of stock markets is a joint study of the spillover of prices and the volatility of prices. Ultimately, it is the perceived importance of the information contained in price movements of other markets that influences investors in the market to which the spillover occurs. In the context of stock markets, studying the transmission of movements of stock returns for a set of markets has become important, and evidence of spillover

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as well as volatility transmission from one market to another market is also quite well-established. Recognizing these important features, modelling volatilities of financial assets in multivariate set-up gained importance since the late 1980's.

In the context of finance literature, it has also long been investigated whether or not the risk of the stock market responds asymmetrically to good and bad news as measured by positive and negative returns, respectively. Particularly, Levy (1974), and Fabozzi and Francis (1977) suggested that there is a need to separate betas between 'bull' and 'bear' markets. Kim and Zumwalt (1979) and Chen (1982) have used threshold model using three threshold levels *viz.*, average monthly market return, average risk free rate, and zero and found no evidence to support the beta instability, but concluded that investors like to receive a positive premium for accepting downside risk, while a negative premium was associated with the up-market beta. More generally, many studies (see, for instance, Bharadwaj and Brooks (1993), Pettengil, Sundaram and Mathur (1995), Howton and Peterson (1998), Crombez and Vandetr Vennet (2000), and Faff (2001), Granger and Silvapulle (2002), Galagedera and Faff (2005)) have examined the validity of the asset pricing models, especially the CAPM, taking into account different market movement like the well known 'bull' and 'bear' markets or the 'up' and 'down' markets. 'Bull' and 'bear' market conditions are mostly defined in the context of stock returns data at monthly/quarterly levels. To classify 'up' and 'down' markets, which are mostly used with high frequency data, various definitions are used. For instance, when realized market returns are above (below) the threshold level, the market is said to be in the up (down) market state. The results are in accordance with the widely held view that the portfolio beta increases (decreases) when the market is bearish (bullish).

In the context of different market conditions, some multivariate studies, especially, those by Longin and Solnik (2001), Ang and Bekaert (2002) and Baele (2005) have shown that during periods of high volatility correlation between markets increases to higher values than its average value. Therefore, it implies modest benefits to portfolio diversification during the down market. Hence, it is very likely that while studying returns and volatility spillovers involving stock returns of two or more countries, consideration of market conditions would yield a more appropriate risk-return relationship in multivariate framework, and consequently a better understanding of the different spillover effects across these stock markets.

It should be mentioned here that in 1988 Bollerslev *et al.*, first proposed the multivariate

GARCH model for the conditional variance-covariance matrix, $H_t$, which is called the VEC model. Engle and Kroner (1995) proposed the BEKK[1] model which can be viewed as a restricted version of the VEC model. Another important direction in which MGARCH model has grown involves modelling the correlations between the series indirectly instead of modelling the conditional variance-covariance matrix directly as in the case of BEKK. Bollerslev (1990) first introduced a class of constant conditional correlation model in which conditional correlation matrix is assumed to be constant, and thus the conditional covariances are proportional to the product of the corresponding conditional standard deviations.

To review the literature on this topic, we first mention the paper by Kasch-Haroutounian and Price (2001). Using daily data from 1994 to 1998, they investigated the interdependences among four central European stock markets (Czech Republic, Poland, Hungary and Slovakia) employing two different formulations of multivariate GARCH – the constant conditional correlation (CCC) model and the BEKK GARCH model. Using the CCC model, the authors have found positive and statistically significant conditional correlation coefficients between Czech and Hungarian stock markets as well as between Hungarian and Polish stock markets. Scheicher (2001) examined the comovements between three European emerging markets *viz.*, the Czech Republic, Poland and Hungary, during 1995 -1997, using vector autoregression-CCC (VAR-CCC) model. His results indicate the presence of both regional and global spillovers in returns but only regional spillovers in volatilities and suggest that global shocks are transmitted to the central European stock market through returns rather than through volatility shocks. The assumption that conditional correlation matrix is time-invariant is unrealistic in many empirical applications. In fact, it is now well established that correlation of stock returns are not constant through time. Correlations tend to rise with economic or equity market integration (see, for details, Erb *et al.* (1994), Longin and Solnik (1995), and Goetznmann *et al.* (2005)).

Tse and Tsui (2002), and Engle (2002) generalized the CCC model to make the conditional correlation matrix time-varying. One particular difficulty for the time-varying conditional correlation model is that the time-varying conditional correlation matrix has to be positive definite for every $t$. The dynamic conditional correlation (DCC) model proposed by Engle (2002), specifies a GARCH-type dynamic matrix process and then transform the variance-covariance matrix to the

[1]An acronym used for the synthesized work on multivariate GARCH model of Baba, Engle, Kraft and Kroner.

correlation matrix. Alternatively, time-varying correlation (TVC) model of Tse and Tsui (2002) formulated the conditional correlation matrix as a weighted sum of past correlations, where the conditional correlation matrix was assumed to resemble an ARMA structure.

The dynamic conditional correlation (DCC) models due to Engle (2002) and Tse and Tsui (2002) are being used increasingly, especially in studies on contagion effects. For instance, Using the CCC model and the smooth transition conditional correlation (STCC) models, Savva and Aslanidis (2010) investigated the stock market integration both among five Central and Eastern European (CEE) countries (Czech Republic, Poland, Hungary, Slovakia, Slovenia) and *vis-a-vis* the aggregate Euro area markets in 1997-2008. Naoui *et al.* (2010) have tested the existence of contagion phenomenon following the US subprime crisis for six developed and ten emerging stock markets. They have concluded that contagion is strong between the US and the developed and emerging countries during the subprime crisis. Hwang *et al.* (2011) have examine the contagion effect of the US subprime crisis on international stock markets using a DCC model on returns data of 38 countries and have found evidence of financial contagion not only in emerging markets but also in developed markets during the US subprime crisis. Bouaziz *et al.* (2012) have tested the contagion effect of the US stock market on the stock markets of developed countries during the subprime financial crisis (2007-2008) by using the same model. They have found that correlations between markets have significantly increased during the US subprime crisis period and accordingly concluded that the crisis has spread across different markets which is a clear evidence of contagion. Very recently, Lean and Teng (2013) have employed the DCC model and presented the trend in degree of financial integration in a time-varying manner. Wang and Moore (2008) have used this model and examined the interdependences between three major emerging markets (the Czech Republic, Poland and Hungary) *vis-a-vis* the aggregate Euro area market. They have found that the financial crisis and the EU enlargement have substantially increased the correlations between Central and Eastern European countries and the Euro area markets. Lanza *et al.* (2006), and Manera *et al.* (2006) have examined correlation and volatility in the oil forward and future markets. Edwards and Susmel (2001), and Edwards and Susmel (2003) investigated the volatility dependence and contagion in equity and interest rate in emerging markets. Balasubramanyan and Susmel (2004) have provided evidence of volatility comovements and spillover from Asian markets. Yang (2005) has used a DCC analysis to examine the role of Japan on the four Asian markets and found that stock market correlations fluctuate widely over time and and volatilities are contagious across markets.

Insofar as the issue of asymmetry in conditional variance matrix are concerned, it may be noted that empirical evidence in univariate models is overwhelmingly in favour of stock markets returns being affected by what is called the 'leverage effect'. However there is hardly any study with asymmetric GARCH in multivariate set-up. Very recently there has been only a few works where DCC models based on EGARCH specification have been used (see, for instannce, Wang *et al.* (2007), Asai (2012), Celik (2012), Gjika and Horvath (2013), Lyocsa *et al.* (2012) and Lean and Teng (2013)).

In our paper we aim to study the return spillover as well as effect of risk from one stock market to another in up and down market conditions, while most of such studies on the differential effects of market conditions are based on returns data of a single stock market. We address this issue for two countries by considering a bivariate GARCH-in-mean model with smooth transition vector autoregressive (VAR) specification in the conditional mean which allows the model to confine switching from one market condition to another. In this model, asymmetry in conditional variance and the likely differential effects of market situations like the up and down markets on conditional mean are duly incorporated. To be more specific, the paper considers the DCC approach for modelling volatility and smooth transition and the VAR model for modelling the conditional mean component. Additionally, the model has a 'in-mean' component in order to be able to capture explicitly the effects of different volatility spillovers on the returns. We have used time series data from two group of countries – developed economies and important emerging economies – to study differences in the nature of different spillover effects across the to market condition among these two groups.

The organization of this paper is as follows. In the next section, we describe the model and methodology used in this paper. Section 3 outlines the several tests of hypotheses of interest. The empirical results are discussed in Section 4. The paper ends with some concluding observations in Section 5.

## 2. The model and methodology

The basic framework of the model proposed in this paper is

$$r_t = \mu_t(\theta) + \varepsilon_t \tag{1}$$

where $r_t$ is an $N \times 1$ vector of returns at time $t$ on $N$ stock indices of $N$ countries, $\mu_t(\theta)$ is the $N \times 1$ conditional mean vector, $\varepsilon_t = H_t^{1/2}(\theta)\eta_t$, $\eta_t$ is an $N \times 1$ random vector with $E(\eta_t) = 0$, $V(\eta_t) = I_N$, $I_N$ is the identity matrix of order $N$, and $\theta$ is a finite vector of parameters. Further, $H_t^{1/2}(\theta)$ is assumed to be an $(N \times N)$ positive definite matrix such that $H_t(\theta)$ is the conditional variance-covariance matrix of $r_t$. Both $H_t(\theta)$ and $\mu_t(\theta)$ depend on the unknown vector $\theta$. Under this assumption on $H_t^{1/2}(\theta)$, $H_t(\theta)$ is also a positive definite matrix, which is now given by the dynamic conditional correlation (DCC) matrix, and the conditional mean model is the smooth transition VAR (STVAR). In this section, we first describe the constant as well as dynamic conditional correlation models and then specify our proposed model.

### *2.1. Constant and dynamic conditional correlation representations*

Bollerslev (1990) proposed a class of MGARCH model in which the conditional correlations are taken to be constant and hence the conditional covariances are proportional to the product of the corresponding conditional standard deviations. These restrictions greatly reduce the number of unknown parameters and thus simplify the estimation of the model.

The constant conditional correlation (CCC) model of $H_t$, based on $N$ stock returns, is defined as:

$$H_t = D_t R D_t = (\rho_{ij}\sqrt{h_{ii,t}h_{jj,t}}) \tag{2}$$

where $D_t = diag(h_{11,t}^{1/2}, \ldots, h_{NN,t}^{1/2})$ , $h_{ii,t}$ is any univariate conditional variance model - most often taken to be the symmetric GARCH but can as well be an asymmetric GARCH specification like the EGARCH or threshold GARCH (TGARCH) (see, Glosten et al. (1993)) and $R = (\rho_{ij})$ is a symmetric positive definite matrix whose elements are the constant conditional correlation $\rho_{ij}$. The original CCC model has the GARCH(1,1) specification for each conditional variance in $D_t$ i.e.,

$$h_{ii,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i h_{ii,t-1} \qquad i = 1, \ldots, N. \tag{3}$$

or, in case of TGARCH model, the volatility specification becomes

$$h_{ii,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + d_i \varepsilon_{i,t-1}^2 I(\varepsilon_{i,t-1} < 0) + \beta_i h_{ii,t-1} \qquad i = 1, \ldots, N. \tag{4}$$

where $I(\cdot)$ is the indicator variable. The $H_t$ matrix defined in equation (2) is positive definite if and only if all the $N$ conditional variances are positive and $R$ is positive definite. The unconditional variances are easily obtained, as in the univariate case, but the unconditional covariances are difficult to compute because of the nonlinearity involved in equation (2). He and Terasvirta (2002) used a VEC-type formulation for $(h_{11,t}, h_{22,t}, \ldots, h_{NN,t})'$, to allow for interactions between the conditional variances, and they called the resultant model as the extended CCC model.

It is quite obvious that the assumption of conditional correlations being constant is unrealistic in many empirical applications. Christodoulakis and Satchell (2002), Engle (2002), and Tse and Tsui (2002) proposed generalizations of the CCC model by making the conditional correlation matrix time dependent. Accordingly, the DCC model is now defined as

$$H_t = D_t R_t D_t = (\rho_{ij,t}\sqrt{h_{ii,t}h_{jj,t}}) \tag{5}$$

where $R_t = (\rho_{ij,t})$, $\rho_{ij,t}$ being the time dependent conditional correlations. The requirement that this $H_t$ is positive definite is guaranteed under simple conditions on the parameters, as stated in Bawens *et al.* (2006).

The DCC model of Christodoulakis and Satchell (2002) uses the Fisher transformation of the correlation coefficient. This model which is only for a bivariate set-up, is easy to implement because the property of positive definiteness of the conditional correlation matrix is guaranteed by the Fisher transformation. The DCC models of Tse and Tsui (2002) and Engle (2002), on the other hand, are genuinely multivariate and are useful when modelling high-dimensional data sets. Though in this study, we consider returns on two stock markets i.e., we take bivariate combinations of the eight markets considered in this work, we take the DCC model of Engle (2002) for our works. The model by Engle (2002) has several advantages compared to other such models. First, it is less restrictive in terms of number of variables included in the model. Second, it accounts for heteroscedasticity by estimating the dynamic correlation coefficients of the standardised residuals. The DCC model of Engle, denoted by $\text{DCC}_\text{E}(1,1)$, is given as

$$R_t = diag(q_{11,t}^{-1/2}, \ldots, q_{NN,t}^{-1/2}) Q_t diag(q_{11,t}^{-1/2}, \ldots, q_{NN,t}^{-1/2}) \tag{6}$$

where the $N \times N$ symmetric positive definite matrix $Q_t = (q_{ij,t})$ is given by:

$$Q_t = (1 - \varphi_1 - \varphi_2)\bar{Q} + \varphi_1 \varepsilon_{t-1}^{*} \varepsilon_{t-1}^{*\prime} + \varphi_2 Q_{t-1} \tag{7}$$

where $\varepsilon_t^* = (\varepsilon_{1t}^*, \ldots, \varepsilon_{Nt}^*)$, $\varepsilon_{it}^* = \varepsilon_{it}/\sqrt{h_{ii,t}}, \quad i = 1, \ldots, N$ and $\varepsilon_{it}$ is the random term associated with the proposed model for $r_t$, as given in equation (8) which follows. $\bar{Q}$ is the $N \times N$ unconditional variance-covariance matrix of $\varepsilon_t^*$, and $\varphi_1$ and $\varphi_2$ are non-negative scalar parameters satisfying $\varphi_1 + \varphi_2 < 1$. It may be noted that unlike the DCC model of Tse and Tsay (2002), this model has the advantage that it does not formulate the conditional correlation as a weighted sum of past correlations. In fact, the matrix $Q_t$ is written as a GARCH equation and then transformed to a correlation matrix. Note that when $\varphi_1 = \varphi_2 = 0$, the $\text{DCC}_\text{E}$ model reduces to the CCC model. This condition can, therefore, be tested for checking if imposing conditional correlations to be constant is empirically relevant.

Engle (2002) has taken $h_{ii,t}$ to be an univariate GARCH model as in equation (3), and then stated the following conditions on the parameters for $H_t$ to be positive definite for all $t$: $(i)$ $\omega_i > 0$, $(ii)$ $h_{ii,0} > 0$, $(iii)$ $\alpha_i$ and $\beta_i$ are such that $h_{iit}$ will be positive with probability one, $i = 1, \ldots, N$, $(iv)$ the roots of the polynomial of GARCH equation lie outside the unit circle, $(v)$ $\varphi_1 > 0$, $(vi)$ $\varphi_2 > 0$, and $(vii)$ $\varphi_1 + \varphi_2 < 1$.

### *2.2. The STVAR-BTGARCH-M model*

The proposed model in this paper, has the framework with $H_t$ being as given in equation (5), and the conditional mean equation being the smooth transition VAR (STVAR) instead of threshold VAR (i.e., TVAR). It may be noted that the advantage of using a smooth transition instead of indicator function is that the former allows for a gradual transition between different regimes (in our case, the two different market movements - up and down) by replacing the indicator function by a continuous function $\boldsymbol{G}[\bar{r}_{it}^k, \gamma]$, most often the logistic function, which changes smoothly from 0 to 1 as $\bar{r}_{it}^k$ increases (see, for details Teresvirta (1994)), where $\bar{r}_{it}^k$ is the average of the past $k$ returns on the $i^{th}$ stock market $(i = 1, 2)$ and the threshold value has been taken to be zero for both the returns. Keeping this modelling advantage in mind, we consider smooth transition in the multivariate set-up for the conditional mean model where due consideration is given to up and down market movements. Now the proposed STVAR-BTGARCH-M model is given by

$$\begin{aligned} r_t = &\left(a^1 + B^1 r_{t-1} + \Lambda^1 \text{vech}\left(H_t\right)\right) \odot (\mathbf{1} - \boldsymbol{G}[\cdot]) \\ &+ \left(a^2 + B^2 r_{t-1} + \Lambda^2 \text{vech}\left(H_t\right)\right) \odot \boldsymbol{G}[\cdot] + \varepsilon_t \end{aligned} \tag{8}$$

where, $r_t = \begin{pmatrix} r_{1t} \\ r_{2t} \end{pmatrix}$, $a^1 = \begin{pmatrix} a_1^1 \\ a_2^1 \end{pmatrix}$, $a^2 = \begin{pmatrix} a_1^2 \\ a_2^2 \end{pmatrix}$, $B^1 = \begin{pmatrix} b_{11}^1 & b_{12}^1 \\ b_{21}^1 & b_{22}^1 \end{pmatrix}$, $B^2 = \begin{pmatrix} b_{11}^2 & b_{12}^2 \\ b_{21}^2 & b_{22}^2 \end{pmatrix}$, $\Lambda^1 = \begin{pmatrix} \lambda_{11}^1 & \lambda_{12}^1 & \lambda_{13}^1 \\ \lambda_{21}^1 & \lambda_{22}^1 & \lambda_{23}^1 \end{pmatrix}$, $\Lambda^2 = \begin{pmatrix} \lambda_{11}^2 & \lambda_{12}^2 & \lambda_{13}^2 \\ \lambda_{21}^2 & \lambda_{22}^2 & \lambda_{23}^2 \end{pmatrix}$, $H_t = \begin{pmatrix} h_{11t} & h_{12t} \\ h_{12t} & h_{22t} \end{pmatrix}$, $\text{vech}(H_t) = \begin{pmatrix} h_{11t} \\ h_{12t} \\ h_{22t} \end{pmatrix}$ and $\varepsilon_t = \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}$. and $\boldsymbol{G}[\cdot] = \begin{pmatrix} g(\bar{r}_{1t}^k, \gamma_1) \\ g(\bar{r}_{2t}^k, \gamma_2) \end{pmatrix}$, $g(\bar{r}_{it}^k, \gamma_i)$, $i = 1, 2$, are the usual logistic functions with parameters $\gamma_1$ and $\gamma_2$ corresponding to two different markets. $H_t$ is the conditional variance-covariance matrix of DCC model as given in equation (5). All other notations has their usual meaning. Superscripts 1 and 2 refer to 'down' and 'up' markets respectively.

A useful feature of the DCC model is that this can be estimated consistently using a two-step procedure (see, Engle and Sheppard (2001), and Bauwens *et al.*, (2006), for details). Under the assumption of bivariate normality of $\varepsilon_t|\psi_{t-1}$ i.e., $\varepsilon_t|\psi_{t-1} \sim N(0, H_t)$, the log-likelihood function (up to a constant), based on $T$ sample observations is given as:

$$L(\theta) = -\frac{1}{2}\sum_{t=1}^{T}(\ln|H_t| + \varepsilon_t' H_t^{-1} \varepsilon_t). \tag{9}$$

Obviously, obtaining ML estimates requires maximizing the log-likelihood function for the $T$ observations with respect to the vector of all parameters of the model,$\theta$. The objective function involved is obviously highly nonlinear and the required part of the programmes were written in Gauss. It may be stated that in order to choose the appropriated value of $k$ several values of $k$ are considered and each one of these values the maximized log likelihood value based on a similar model at univariate level is obtained. The value of $k$ for which the value is the highest is then taken to be the value of $k$.

## 3. Testing of hypothesis

We test for spillovers in means, variances, and 'BTGARCH-in-mean' effects for the proposed model in equation (8) by placing appropriate restrictions on the relevant parameters and carrying out the Wald test.

Now we state the different null hypotheses which specify the absence of each of the three different kinds of spillovers or transmissions for each of the two market movements as well as equality of spillovers in the two market movements.

1. *Tests of spillovers in conditional mean*
   (a) $H_{01}^{a}$: No spillovers in mean from second stock market to first stock market in both up and down market movements i.e., $b_{12}^{1} = b_{12}^{2} = 0$.
   (b) $H_{01}^{b}$: No spillovers in mean from first stock market to second stock market in both up and down market movements i.e., $b_{21}^{1} = b_{21}^{2} = 0$.
2. *Tests of equality of spillovers in the two stock market movements - up and down*
   (a) $H_{02}^{a}$: Equal spillovers in mean in up and down market conditions, from second market to first market i.e., $b_{12}^{1} = b_{12}^{2}$.
   (b) $H_{02}^{b}$: Equal spillovers in mean in up and down market conditions, from first market to second market i.e., $b_{21}^{1} = b_{21}^{2}$.
3. *Tests of no BTGARCH-in-mean effect from one market to another*
   (a) No asymmetry in own risk-return relation in first market i.e., $H_{03}^{a}$: $\lambda_{11}^{1} = \lambda_{11}^{2} = 0$.
   (b) No asymmetric spillovers of risk of second stock market to the mean of first stock market i.e., $H_{03}^{b}$: $\lambda_{13}^{1} = \lambda_{13}^{2}$.
   (c) No asymmetry in own risk-return relation in second market i.e., $H_{03}^{c}$: $\lambda_{23}^{1} = \lambda_{23}^{2} = 0$.
   (d) No asymmetric spillovers of risk of first stock market to the mean of second stock market i.e., $H_{03}^{d}$: $\lambda_{21}^{1} = \lambda_{21}^{2}$.
4. *Test of equality of each of the parameters of BTGARCH-in-mean effects in up and down market movements*
   $H_{04}$: $\lambda_{11}^{1} = \lambda_{11}^{2}$; $\lambda_{12}^{1} = \lambda_{12}^{2}$; $\lambda_{13}^{1} = \lambda_{13}^{2}$; $\lambda_{21}^{1} = \lambda_{21}^{2}$; $\lambda_{22}^{1} = \lambda_{22}^{2}$; $\lambda_{23}^{1} = \lambda_{23}^{2}$.
5. *Test of asymmetric volatility (due to leverage effect) of the two stock markets*
   No asymmetric volatility i.e., $H_{05}$: $d_1 = d_2 = 0$.
6. *Test of dynamic conditional correlation*
   No dynamic conditional correlation i.e., $H_{06}$: $\varphi_1 = \varphi_2 = 0$.

## 4. Empirical Results

In this section we discuss the results of estimation of the model proposed in this paper. We begin with describing the data sets used and also the results of some standard statistical tests which have been carried out to find the characteristics of these time series.

*4.1. Data and summary statistics*

Stock index data at daily frequency for eight countries - four from developed countries and four from important emerging economics - have been considered for this study. Specifically, the countries in these two groups are the USA, the UK, Hong Kong and Japan for the developed economics, and Brazil, Russia, India and China for the important emerging economies. The choice of these two groups of countries has been made from consideration of the fact that stock markets of developed economies are well developed, structured, and these have time-tested, well-established trading rules and also strong regulatory authorities while these important emerging economies lag behind in respect of some of these. Further, although these BRIC countries have immense economic potential and their global influence has come through for quite some time, the gap between the developed countries and this group is still substantial. Hence, it is quite possible that the investors' sentiments and reactions are likely to be somewhat different in terms of the risk-return relationship for these two groups, especially in different market situations.

Table 1: Summary statistics of daily stock returns on the eight stock markets

| Country / Summary | Brazil | Russia | India | China | The US | The UK | Hong Kong | Japan |
|---|---|---|---|---|---|---|---|---|
| Mean | 0.0399 | 0.0661 | 0.0396 | 0.0152 | -0.0006 | -0.0004 | 0.0082 | -0.0189 |
| Median | 0.0937 | 0.1526 | 0.1117 | 0.0000 | 0.0488 | 0.0402 | 0.0286 | 0.0051 |
| Maximum | 13.6766 | 25.2261 | 15.9899 | 9.4007 | 10.9572 | 8.8107 | 13.4068 | 13.2345 |
| Minimum | -12.0961 | 20.6571 | -11.8092 | -9.2561 | -9.4695 | -8.7099 | -13.5820 | -12.1110 |
| Std. dev. | 1.9048 | 2.3290 | 1.6517 | 1.5882 | 1.3508 | 1.2385 | 1.6158 | 1.5667 |
| Skewness | -0.0953 | -0.1960 | -0.1777 | -0.0831 | -0.1584 | -0.1767 | -0.0657 | -0.3933 |
| Kurtosis | 6.6994 | 15.4304 | 9.3485 | 7.5141 | 10.3268 | 8.7030 | 10.5496 | 9.6856 |
| J-B | 1837.04 | 2086.92 | 5466.37 | 2829.46 | 7323.49 | 4479.70 | 7703.89 | 6023.19 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| ADF | -55.8956 | -54.5714 | -53.1177 | -57.4490 | -44.8862 | -29.4025 | -57.9345 | -58.0037 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| $Q(5)$ | 13.8192 | 12.1271 | 21.5550 | 10.2975 | 42.0542 | 48.4091 | 7.5071 | 7.0895 |
| | (0.02) | (0.03) | (0.00) | (0.07) | (0.00) | (0.00) | (0.19) | (0.21) |
| $Q(10)$ | 23.1694 | 15.7780 | 38.5307 | 18.9498 | 49.1160 | 64.2120 | 17.7793 | 14.1138 |
| | (0.01) | (0.11) | (0.00) | (0.04) | (0.00) | (0.00) | (0.06) | (0.17) |

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| Country Summary | Brazil | Russia | India | China | The US | The UK | Hong Kong | Japan |
|---|---|---|---|---|---|---|---|---|
| $Q^2(5)$ | 943.6102 | 560.6082 | 522.6123 | 250.7641 | 1340.2018 | 1302.9052 | 1351.6053 | 1617.4151 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| $Q^2(10)$ | 1903.1032 | 835.0211 | 845.1342 | 454.6938 | 2609.1054 | 2122.8019 | 2026.8029 | 2589.5043 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| $D_{max}$ | 6.82 | 7.62 | 14.37 | 11.46 | 14.66 | 14.67 | 8.56 | 5.31 |
| $WD_{max}$ | 9.89 | 12.34 | 18.18 | 14.49 | 14.66 | 18.57* | 10.17 | 9.44 |

Figures in parentheses indicate $p-$values. J-B stands for the Jarque-Bera normality test. Unit root test is based on augmented Dickey-Fuller (ADF) test with linear trend and intercept terms. $D_{max}$ and $WD_{max}$ are the test for structural stability (Bai and Perron (1998, 2003)). * indicate significance at 1% level (critical value at 1% level is 15.41 in case of $D_{max}$ test, and the same is 17.01 in case of $WD_{max}$ test.).

In all these countries, more than one index on stock prices are available. We have, however, taken only one index for each country. Accordingly, the stock indices considered are: BOVESPA (for Brazil), MICEX (for Russia), SENSEX (for India), SSE COMPOSITE (for China), S&P 500 (for the US), FTSE ALL (for the UK), HANG SENG (for Hong Kong) and NIKKEI 225 (for Japan). All the time series have been downloaded from the official website of Yahoo Finance. The time period for all the time series is from 01 January 2000 to 31 December 2012. The total number of observations are not the same for all the eight series because of varying number of holidays in different countries when stock markets remain closed. However, for the purpose of this study, we have taken data for those dates only for which data for all the stock indices are available. The total number of observations obtained is 2586. All stock price indices are taken in logarithmic values and then computed in percentage i.e., $r_t = \ln(\frac{p_t}{p_{t-1}}) \times 100$, where $p_t$ is the stock price index of a country on the $t^{th}$ day. $r_t$ is called the compounded rate of returns in percentage.

The summary statistics on the returns of the eight time series are presented In Table 1, we presents the summary statistics *viz.*, mean, median, maximum, minimum, standard deviation, skewness, kurtosis, Jarque-Bera normality test(JB), unit root test (ADF), the autocorrelation tests of return and the squared return and the test of multiple structural break (Bai-Perron).The mean returns for all the BRIC countries are positive while all but returns on the HANG SENG of Hong Kong, among the developed market, are negative . All the series are negatively skewed, although small in magnitude and show the typical high kurtosis of the high frequency financial time series. Non-normality is also a feature of financial time series (see the JB test result) and it is due to fat tail nature of financial data.

The stationarity or nonstationarity of the return series and the probable existence of structural break in each series was examined. All the series are found to have unit roots at their level i.e., stock price, values by the augmented Dickey Fuller (ADF) test. However, the ADF test statistic values on returns confirm that all the returns series are stationary. In the ADF estimating equation, the linear deterministic trend term is statistically insignificant for all the series. Also, all the return series except NIKKEI 225 of Japan are found to have significant (linear) autocorrelations as exhibited by the Ljung-Box ($LB(Q)$) test with 5 and 10 lag. Ljung-Box ($LB(Q)$) test statistic, with the same lag, for the squared return, are highly significant, implying the presence of an ARCH type process for the conditional variance.

Finally, the structural stability of each of the series during the sample period has been examined by carrying out the Bai-Perron test (1998, 2003). This test which is used widely for testing the presence of multiple structural breaks envisages a two-step procedure. In the first step, Bai and Perron proposed two test statistics, called the $D_{max}$ and $WD_{max}$, for testing the null hypothesis of 'no structural break' against the alternative of 'the number of breaks/changes is arbitrary/unknown, but up to some specified maximum. In case either of these tests reject the null hypothesis of 'no structural break', then in the second stage a sequential test procedure designated as $SupF(2|1)$, $SupF(3|2)$, *etc.* is to be applied. It is evident from the $D_{max}$ test statistic values presented in Table 1 that the computed values are less than the critical value of 5.4 for all the eight returns series at 1% level of significance, leading to the conclusion that the null hypothesis of 'no structural break' cannot be rejected, and hence all the series are structurally stable. The conclusion by the $WD_{max}$ test remains the same for all but SENSEX (India) and FTSE ALL (the UK) indices. For this two series, the test statistic values have been found to have just exceeded the critical value of 17.01 at 1% level of significance. Combining these findings, it can be concluded that all the eight series are structurally stable.

### *4.2. Findings on the models*

The proposed STVAR-BTGARCH-M model, specified in equations (5) through (8), which is based on the DCC approach, has been estimated by the ML method of estimation. The estimates of the parameters of the model are presented in Table 2 through Table 4. It may be mentioned that we have also carried out estimation of the parameters of another model, called STVAR-BGARCH-M model, where the market movements are duly modelled in the mean part while the variance-covariance matrix is taken to be symmetric bivariate GARCH. The purpose of taking of this model is to find to what extent consideration of asymmetry in $H_t$ improves the performance as opposed to symmetric $H_t$ when the DCC approach is being considered. We are not presenting the estimates of STVAR-BGARCH-M model separately for brevity of space. For the purpose of comparison with our final proposed model, it is sufficient to report the maximized log-likelihood values of the model for the different pairs.

*4.2.1. Parameters capturing the mean spillover*

First we discuss, in Table 2, about the estimates of the parameters signifying the mean spillover in both down and up markets captured by our proposed STVAR-BTGARCH-M model. The evidence of mean spillover effects from one stock market to another is overwhelming irrespective of the combination of countries considered. In particular, among the six pairs of four developed countries, $b^1_{21}$ and $b^2_{21}$ is significant and positive except Hong Kong-Japan in up market. Here the value of the coefficient is $-0.0223$ which is insignificant. In case of spillover from the UK and Japan to the US in down market, i.e., $b^1_{12}$, is negative whereas this effect, i.e., $b^2_{12}$ is significantly positive in the up market. The opposite happens in the combination of the US-Hong Kong and Hong Kong-Japan and the UK-Japan, where $b^1_{12}$ is positive and $b^2_{12}$ is negative. But a little difference in the UK-Japan is that the coefficients are statistically insignificant in both the market conditions. As per the $b^i_{21}$ $(i = 1, 2)$ is concerned, though it is significantly positive in both the market conditions in all but one pair, it may be mentioned that in case of the US-Hong Kong, the US-Japan, and the UK-Hong Kong this spillover is greater in magnitude in case of down market than in up market. In case of the UK-Japan the effect is less in down market than in up market.

Next we discuss about the pairs of emerging markets. Among the emerging groups the significant negative spillover comes only from China to Russia and to India in the up market. In case of Brazil-China combination, the coefficient $b^i_{21}$ $(i = 1, 2)$, i.e., spillover from China to Brazil in both market conditions are found to be negative and statistically insignificant. The only positive spillover from China among the emerging group is found in case of India-China combination in down market and it is significant in 10% level. In all the other cases, we have found positive return spillovers from one market to another. But in general it can be noted that spillover effect is greater in case of up market than in down market. In particular, mean spillover from Russia to Brazil is statistically insignificant in down market but significant in up market. The same effect from Brazil to Russia, to India and to China is greater in up market than in down market respectively. This implies that emerging markets are more correlated in up market condition than in down market.

Table 2: Estimates of the parameters for the mean spillover

| | Parameters in the down market condition | | | | | | Parameters in the up market condition | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $a_1^1$ | $b_{11}^1$ | $b_{12}^1$ | $a_2^1$ | $b_{21}^1$ | $b_{22}^1$ | $a_1^2$ | $b_{11}^2$ | $b_{12}^2$ | $a_2^2$ | $b_{21}^2$ | $b_{22}^2$ |
| **Developed-Developed combination** | | | | | | | | | | | | |
| US-UK | 0.0558 | -0.0133 | -0.0726 | -0.171 | 0.3364 | -0.2614 | -0.032 | -0.0988 | 0.0656 | 0.1214 | 0.3312 | -0.0072 |
| | (0.03) | (0.65) | (0.00) | (0.00) | (0.00) | (0.00) | (0.24) | (0.00) | (0.00) | (0.00) | (0.00) | (0.76) |
| US-HO | -0.222 | -0.0796 | 0.072 | -0.1465 | 0.5494 | -0.0741 | 0.1116 | -0.0751 | -0.0881 | 0.026 | 0.3776 | -0.1609 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.44) | (0.00) | (0.00) |
| US-JAP | -0.2397 | -0.1175 | -0.0276 | -0.1535 | 0.492 | -0.0304 | 0.1565 | -0.0126 | 0.0351 | 0.1591 | 0.4539 | -0.161 |
| | (0.00) | (0.00) | (0.05) | (0.01) | (0.00) | (0.03) | (0.00) | (0.50) | (0.01) | (0.00) | (0.00) | (0.00) |
| UK-HO | 0.0307 | -0.0367 | -0.0303 | -0.0375 | 0.342 | -0.1922 | 0.0028 | -0.0679 | 0.017 | -0.0169 | 0.3202 | -0.0763 |
| | (0.03) | (0.15) | (0.08) | (0.02) | (0.00) | (0.00) | (0.92) | (0.00) | (0.21) | (0.76) | (0.00) | (0.00) |
| UK-JAP | 0.0409 | -0.053 | 0.0216 | -0.0528 | 0.3563 | -0.132 | 0.0401 | -0.0407 | -0.006 | 0.1322 | 0.4044 | -0.1271 |
| | (0.00) | (0.02) | (0.25) | (0.00) | (0.00) | (0.00) | (0.03) | (0.03) | (0.64) | (0.00) | (0.00) | (0.00) |
| HO-JAP | 0.0105 | -0.0663 | 0.0338 | -0.0888 | 0.0264 | -0.0253 | 0.126 | 0.0337 | -0.093 | 0.1523 | -0.0223 | -0.018 |
| | (0.33) | (0.00) | (0.01) | (0.00) | (0.01) | (0.07) | (0.00) | (0.00) | (0.00) | (0.00) | (0.19) | (0.08) |
| **Emerging-Emerging combination** | | | | | | | | | | | | |
| BR-RUS | -0.1157 | -0.0452 | 0.0141 | 0.2068 | 0.1144 | -0.0387 | 0.3257 | 0.0171 | 0.0388 | 0.2473 | 0.2167 | -0.0439 |
| | (0.00) | (0.04) | (0.44) | (0.00) | (0.00) | (0.07) | (0.00) | (0.46) | (0.02) | (0.00) | (0.00) | (0.02) |
| BR-IND | -0.0629 | -0.0395 | 0.0232 | 0.1243 | 0.093 | 0.0074 | 0.203 | 0.0309 | 0.0138 | 0.1802 | 0.1284 | 0.0125 |
| | (0.25) | (0.05) | (0.33) | (0.00) | (0.00) | (0.76) | (0.00) | (0.20) | (0.46) | (0.00) | (0.00) | (0.42) |
| BR-CH | -0.0841 | -0.0145 | -0.0181 | -0.2533 | 0.0451 | -0.0325 | 0.0826 | 0.0246 | -0.0063 | 0.0613 | 0.101 | -0.0274 |
| | (0.01) | (0.25) | (0.28) | (0.00) | (0.00) | (0.03) | (0.00) | (0.26) | (0.69) | (0.00) | (0.00) | (0.05) |
| RUS-IND | 0.164 | 0.004 | -0.0202 | 0.0047 | 0.0921 | -0.0309 | 0.1862 | 0.0198 | 0.0237 | 0.1566 | 0.0705 | 0.0236 |
| | (0.03) | (0.82) | (0.50) | (0.89) | (0.00) | (0.14) | (0.00) | (0.23) | (0.25) | (0.00) | (0.00) | (0.12) |
| RUS-CH | 0.0956 | 0.0056 | 0.0029 | -0.2546 | 0.0016 | -0.0218 | 0.2374 | 0.0495 | -0.0533 | 0.0132 | 0.0592 | -0.0256 |
| | (0.02) | (0.59) | (0.92) | (0.00) | (0.93) | (0.08) | (0.00) | (0.01) | (0.00) | (0.37) | (0.00) | (0.02) |
| IND-CH | -0.0265 | -0.013 | 0.019 | 0.037 | 0.0196 | -0.0029 | 0.1386 | 0.026 | -0.0257 | 0.0707 | 0.0408 | -0.0112 |
| | (0.01) | (0.36) | (0.09) | (0.01) | (0.05) | (0.77) | (0.00) | (0.01) | (0.06) | (0.00) | (0.00) | (0.31) |
| **Developed-Emerging combination** | | | | | | | | | | | | |
| US-BR | 0.033 | -0.0215 | -0.1676 | -0.16 | -0.0091 | -0.0243 | 0.22 | -0.0384 | 0.1344 | 0.3931 | 0.1583 | -0.016 |
| | (0.79) | (0.78) | (0.00) | (0.28) | (0.90) | (0.61) | (0.07) | (0.59) | (0.00) | (0.04) | (0.02) | (0.71) |
| US-RUS | -0.1154 | -0.1833 | -0.0539 | -0.0454 | 0.2637 | -0.0568 | 0.0923 | 0.0514 | 0.0401 | 0.3549 | 0.261 | -0.0362 |
| | (0.04) | (0.01) | (0.19) | (0.78) | (0.00) | (0.28) | (0.12) | (0.48) | (0.28) | (0.01) | (0.00) | (0.42) |
| US-IND | -0.0316 | -0.0864 | -0.0461 | 0.0076 | 0.2319 | -0.0123 | 0.0355 | -0.0423 | 0.0071 | 0.1134 | 0.2957 | 0.0132 |
| | (0.16) | (0.00) | (0.00) | (0.87) | (0.00) | (0.59) | (0.03) | (0.02) | (0.55) | (0.00) | (0.00) | (0.35) |
| US-CH | | | | | | | | | | | | |
| UK-BR | 0.0195 | -0.0885 | 0.0726 | -0.12 | 0.0004 | -0.0287 | 0.1915 | -0.0722 | 0.0735 | 0.3706 | 0.1331 | -0.0491 |
| | (0.11) | (0.00) | (0.00) | (0.00) | (0.97) | (0.02) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-RUS | 0.0562 | -0.035 | -0.0012 | 0.1808 | -0.0129 | 0.0082 | 0.027 | -0.0805 | 0.0143 | 0.2646 | 0.0344 | 0.0059 |
| | (0.01) | (0.06) | (0.93) | (0.00) | (0.45) | (0.51) | (0.26) | (0.00) | (0.06) | (0.00) | (0.35) | (0.72) |
| UK-IND | 0.0827 | -0.0523 | -0.0034 | 0.0577 | 0.1586 | -0.0417 | 0.1483 | -0.0515 | 0.0145 | 0.1761 | 0.1482 | 0.0092 |
| | (0.00) | (0.05) | (0.83) | (0.44) | (0.00) | (0.17) | (0.00) | (0.01) | (0.41) | (0.00) | (0.00) | (0.65) |
| UK-CH | -0.01 | -0.0331 | -0.0219 | -0.2551 | 0.0535 | -0.0308 | 0.0132 | -0.046 | 0.0141 | 0.0061 | 0.1633 | -0.0353 |

*continued on next page*

Table: 2 continued from previous page

| | **Parameters in the down market condition** | | | | | | **Parameters in the up market condition** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $a_1^1$ | $b_{11}^1$ | $b_{12}^1$ | $a_2^1$ | $b_{21}^1$ | $b_{22}^1$ | $a_1^2$ | $b_{11}^2$ | $b_{12}^2$ | $a_2^2$ | $b_{21}^2$ | $b_{22}^2$ |
| | (0.45) | (0.05) | (0.12) | (0.00) | (0.01) | (0.04) | (0.70) | (0.00) | (0.19) | (0.86) | (0.00) | (0.03) |
| HO-BR | 0.0445 | -0.086 | 0.2145 | 0.1296 | -0.0264 | -0.0221 | 0.1701 | -0.0857 | 0.1965 | 0.1675 | 0.0489 | -0.0372 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.03) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| HO-RUS | -0.0429 | -0.0686 | 0.0891 | 0.1604 | -0.0052 | -0.0031 | -0.0123 | -0.0302 | 0.0763 | 0.2434 | 0.0094 | 0.0237 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.59) | (0.75) | (0.65) | (0.00) | (0.00) | (0.00) | (0.47) | (0.16) |
| HO-IND | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| HO-CH | 0.0289 | -0.0233 | -0.025 | -0.1618 | -0.0531 | -0.0131 | 0.0181 | 0.0275 | -0.0033 | 0.0173 | 0.0169 | -0.012 |
| | (0.22) | (0.33) | (0.28) | (0.01) | (0.00) | (0.51) | (0.73) | (0.16) | (0.83) | (0.83) | (0.48) | (0.59) |
| JAP-BR | -0.0384 | -0.0668 | 0.2508 | -0.1216 | -0.0436 | -0.0017 | 0.164 | -0.1003 | 0.1777 | -0.1116 | 0.0593 | 0.0253 |
| | (0.12) | (0.00) | (0.00) | (0.00) | (0.08) | (0.92) | (0.01) | (0.00) | (0.00) | (0.39) | (0.02) | (0.28) |
| JAP-RUS | -0.0432 | -0.0581 | 0.1349 | 0.1222 | -0.0172 | 0.014 | 0.0606 | -0.0648 | 0.1059 | 0.2229 | 0.0154 | 0.0296 |
| | (0.10) | (0.00) | (0.00) | (0.12) | (0.36) | (0.39) | (0.12) | (0.00) | (0.00) | (0.00) | (0.53) | (0.09) |
| JAP-IND | -0.0837 | -0.0436 | 0.0966 | 0.0141 | 0.098 | -0.0069 | 0.0483 | -0.0758 | 0.0948 | -0.0738 | 0.0291 | 0.0076 |
| | (0.00) | (0.01) | (0.00) | (0.61) | (0.00) | (0.72) | (0.45) | (0.00) | (0.00) | (0.07) | (0.16) | (0.72) |
| JAP-CH | 0.0322 | 0.0341 | -0.0468 | -0.147 | -0.0578 | 0.0117 | 0.2093 | -0.0386 | -0.0235 | 0.3531 | 0.0135 | -0.0373 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.26) | (0.00) | (0.00) | (0.10) | (0.00) | (0.38) | (0.00) |

$p-$values are given in parenthesis.

We now focus on the spillover among the develop and emerging market combination. It should be noted that spillovers from the US and the UK to the emerging countries in both market conditions are either positive or statistically insignificant. The positive and statistically significant effects are found in case of the US-Russia, the US-India, the UK-India and the UK-China in down market and all combinations with the US and UK with emerging countries except the UK-Russia are positive with 5% level of significant. In case of the combination of Hong Kong and Japan with emerging markets, we have also found that the estimated coefficients capturing spillovers from China to Hong Kong and Japan are negative in two different market conditions, but statistically significant only for Japan. For the other cases, ie. Brazil, Russia and India to Hong Kong and Japan are positive. In the reverse direction, i.e., effects from Hong Kong to the emerging markets are negative in down market and positive in up market. Hence, our findings strongly provide support, in general, to asymmetric return spillovers in the up and down market conditions among all type of combinations of developed and emerging markets.

*4.2.2. Estimates of the parameters of volatility-return relation*

We now discuss about the spillover effects with reference to the 'BTGARCH-in-mean' component of the STVAR-BTGARCH-M model. In other words, we discuss how the risk of one market affects the returns of another market in both up and down market situations. Looking at the developed markets combinations, we find that the own spillover effects on this count are mostly significant. It is only in case of US-UK pair and UK-Hong Kong pair - both in down market - that we find neither of the markets in both cases have significant own spillover effects. Similar is the finding for the six pairs in emerging-emerging combination in down market. In all, there are four cases where the own spillover effects are insignificant. These are: each of Russia and India in Russia-India pair, Russia in Brazil-Russia pair, and Russia in Russia-China pair. In the developed-emerging combination of pairs, we find that the own spillover effects is insignificant in the following cases in the down market: both the US and Brazil have no own spillover effects, and so are the cases with the US and India, the UK and Russia, and Japan and Brazil. Also, Brazil in UK-Brazil pair, the UK in UK-China pair and Japan in Japan-Russia pair show no own spillover effect.

In case of up market, in Table 3, there are only five cases where own spillover effects are insignificant. These are the US in US-UK pair, the UK in UK-Hong Kong pair, the UK in UK-Japan pair, Japan in US-Japan pair and Japan in UK-Japan pair. In the combination of emerging markets, there are six such cases which are as follows: each of Brazil and India in Brazil-India pair, each of India and China in India-China pair, Brazil in Brazil-China pair, and India in Russia-India pair. In case of up market, we note that there is no own spillover effect for both the US and Brazil, the US and India, and Japan and Russia. The other cases where only one country in a pair has no spillover effects of its own are: the UK in UK-Brazil, Russia in UK-Russia, the UK in UK-China, Brazil in Hong Kong-Brazil, Russia in Hong Kong-Russia, and China in Hong Kong-China.

Looking at the estimates of $\lambda_{21}^1$ and $\lambda_{13}^1$ which stand for the cross country risk-return relation in down market, we find that in the developed-developed combination, this effect is significant both ways in all the six cases except for risk of the UK having no significant effect on the mean returns of the US. This establishes that the returns of any developed stock market is significantly affected by the risk of another developed market except for the case mentioned. We may also note that the estimates of all the coefficients are found to be positive except for the US-UK pair. In the up market situation, the observations on the statistical significance of the two relevant parameters *viz.*, $\lambda_{21}^2$ and $\lambda_{13}^2$, are that for all combinations both the coefficients are significant. However, it is also to be noted that $\lambda_{21}^2$ is found to have negative estimate for all but the US-UK pair. As regards $\lambda_{13}^2$ there are two pairs (US-Japan and UK-Hong Kong) where the sign is negative. Insofar as the six pairs of the emerging-emerging combinations are concerned, except for $\lambda_{21}^1$ in case of Brazil-India, Russia-India, and $\lambda^1_{13}$ in Brazil-India, all others are significant. In particular, it may be noted that the risk of Brazil stock market does not affect the returns on Indian stock market and *vice versa*. One striking observation for this down market movement is that both the coefficients are found to be negative in all the six pairs in this combination.

Table 3: Estimates of the parameters of the volatility-return relation

| | **Parameters in the down market condition** | | | | | | **Parameters in the up market condition** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\lambda^1_{11}$ | $\lambda^1_{12}$ | $\lambda^1_{13}$ | $\lambda^1_{21}$ | $\lambda^1_{22}$ | $\lambda^1_{23}$ | $\lambda^2_{11}$ | $\lambda^2_{12}$ | $\lambda^2_{13}$ | $\lambda^2_{21}$ | $\lambda^2_{22}$ | $\lambda^2_{23}$ |
| **Developed-Developed combination** | | | | | | | | | | | | |
| US-UK | 0.0125 | -0.0401 | 0.025 | 0.0055 | -0.0482 | 0.0323 | -0.0223 | 0.1391 | -0.0537 | -0.0615 | 0.0523 | 0.0305 |
| | (0.62) | (0.00) | (0.18) | (0.85) | (0.34) | (0.18) | (0.56) | (0.00) | (0.06) | (0.05) | (0.02) | (0.09) |
| US-HO | 0.0289 | 0.0395 | -0.0221 | 0.0219 | 0.107 | -0.0344 | 0.0334 | -0.0683 | 0.0427 | -0.0782 | 0.0631 | 0.1252 |
| | (0.02) | (0.04) | (0.05) | (0.19) | (0.00) | (0.01) | (0.02) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| US-JAP | 0.0212 | 0.0793 | -0.035 | -0.0224 | 0.1082 | 0.028 | 0.0308 | -0.0433 | 0.0192 | -0.0559 | -0.1052 | 0.0025 |
| | (0.09) | (0.00) | (0.01) | (0.09) | (0.00) | (0.03) | (0.07) | (0.00) | (0.14) | (0.00) | (0.00) | (0.93) |
| UK-HO | -0.0173 | 0.13 | -0.0207 | -0.0618 | 0.1801 | -0.0137 | -0.0151 | -0.0454 | 0.0052 | 0 | -0.1725 | 0.0905 |
| | (0.12) | (0.00) | (0.02) | (0.00) | (0.00) | (0.17) | (0.17) | (0.04) | (0.68) | (1.00) | (0.00) | (0.00) |
| UK-JAP | -0.0401 | 0.1264 | -0.0041 | -0.1151 | 0.1943 | 0.0199 | 0.0148 | -0.0879 | -0.0134 | -0.1464 | 0.1098 | -0.0126 |
| | (0.00) | (0.00) | (0.67) | (0.00) | (0.00) | (0.03) | (0.35) | (0.00) | (0.34) | (0.00) | (0.00) | (0.75) |
| HO-JAP | -0.0527 | 0.1556 | -0.0469 | -0.0814 | 0.2125 | -0.0377 | 0.0342 | -0.0701 | -0.0176 | 0.028 | 0.1211 | -0.1633 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.07) | (0.04) | (0.00) | (0.00) |
| **Emerging-Emerging combination** | | | | | | | | | | | | |
| BR-RUS | 0.0557 | -0.1037 | 0.0156 | -0.0117 | -0.0494 | 0.0131 | -0.1128 | 0.0779 | -0.0014 | -0.0162 | -0.134 | 0.0324 |
| | (0.00) | (0.00) | (0.07) | (0.43) | (0.00) | (0.25) | (0.00) | (0.00) | (0.88) | (0.20) | (0.00) | (0.00) |
| BR-IND | 0.035 | -0.0261 | -0.0043 | -0.0285 | -0.0353 | 0.027 | -0.0197 | 0.0429 | -0.0368 | -0.0408 | 0.1358 | -0.0121 |
| | (0.04) | (0.62) | (0.78) | (0.02) | (0.17) | (0.10) | (0.40) | (0.00) | (0.11) | (0.15) | (0.12) | (0.72) |
| BR-CH | 0.0287 | -0.0633 | 0.0097 | 0.002 | -0.0237 | 0.0645 | -0.0108 | 0.052 | -0.0001 | -0.0082 | -0.1279 | 0.0414 |
| | (0.00) | (0.00) | (0.49) | (0.83) | (0.02) | (0.00) | (0.30) | (0.00) | (0.99) | (0.41) | (0.00) | (0.00) |
| RUS-IND | 0.012 | -0.019 | -0.0152 | -0.001 | -0.0264 | 0.0129 | -0.0225 | 0.0323 | -0.0082 | 0.0238 | -0.0908 | -0.0109 |
| | (0.27) | (0.36) | (0.24) | (0.85) | (0.11) | (0.36) | (0.04) | (0.12) | (0.55) | (0.00) | (0.00) | (0.44) |
| RUS-CH | 0.0084 | -0.0547 | -0.0051 | 0.0056 | -0.0663 | 0.0677 | -0.0336 | 0.0724 | -0.0083 | 0.0104 | -0.1237 | 0.0224 |
| | (0.36) | (0.00) | (0.73) | (0.24) | (0.00) | (0.00) | (0.00) | (0.00) | (0.40) | (0.11) | (0.00) | (0.06) |
| IND-CH | 0.0194 | -0.0653 | -0.0057 | -0.0007 | -0.0342 | -0.0174 | 0.0032 | 0.0998 | -0.0136 | 0.0145 | -0.1036 | 0.0179 |
| | (0.05) | (0.00) | (0.59) | (0.94) | (0.00) | (0.08) | (0.74) | (0.00) | (0.16) | (0.14) | (0.00) | (0.12) |
| **Developed-Emerging combination** | | | | | | | | | | | | |
| US-BR | -0.0073 | 0.1876 | -0.084 | -0.0857 | 0.2263 | -0.0271 | 0.0324 | -0.1433 | -0.019 | 0.1552 | -0.2152 | -0.0576 |
| | (0.96) | (0.58) | (0.39) | (0.62) | (0.57) | (0.81) | (0.82) | (0.57) | (0.79) | (0.41) | (0.61) | (0.64) |
| US-RUS | 0.2172 | -0.4829 | 0.0248 | 0.3744 | -1.2657 | 0.1277 | -0.2579 | 0.6028 | -0.0341 | -0.9162 | 2.9982 | -0.296 |
| | (0.00) | (0.00) | (0.18) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.10) | (0.00) | (0.00) | (0.00) |
| US-IND | 0.0142 | -0.003 | -0.002 | -0.0256 | 0.042 | 0.0061 | 0.0173 | 0.093 | -0.0315 | 0.0302 | 0.0825 | -0.0187 |
| | (0.19) | (0.84) | (0.78) | (0.02) | (0.00) | (0.63) | (0.19) | (0.00) | (0.00) | (0.11) | (0.00) | (0.33) |
| US-CH | | | | | | | | | | | | |
| UK-BR | 0.0001 | 0.1645 | -0.0504 | -0.1345 | 0.3035 | -0.0096 | -0.0104 | -0.103 | -0.0337 | 0.1005 | -0.2508 | -0.0468 |
| | (1.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.27) | (0.31) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-RUS | 0.0738 | -0.0723 | -0.0017 | 0.069 | -0.2002 | 0.0197 | -0.0737 | 0.0629 | -0.0091 | -0.1034 | 0.0407 | -0.0138 |
| | (0.12) | (0.46) | (0.90) | (0.00) | (0.00) | (0.12) | (0.00) | (0.00) | (0.09) | (0.00) | (0.00) | (0.39) |
| UK-IND | 0.0711 | -0.2079 | 0.0114 | -0.0924 | 0.2929 | -0.0325 | -0.1177 | 0.3341 | -0.0879 | -0.0857 | 0.5394 | -0.0932 |
| | (0.02) | (0.02) | (0.22) | (0.00) | (0.00) | (0.07) | (0.00) | (0.00) | (0.00) | (0.03) | (0.00) | (0.00) |
| UK-CH | 0.0072 | 0.1388 | -0.0006 | -0.0188 | 0.1104 | 0.0674 | -0.0024 | -0.1458 | 0.0014 | 0.0163 | -0.1318 | 0.0326 |

*continued on next page*

Table: 3 continued from previous page

| | Parameters in the down market condition | | | | | | Parameters in the up market condition | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\lambda^1_{11}$ | $\lambda^1_{12}$ | $\lambda^1_{13}$ | $\lambda^1_{21}$ | $\lambda^1_{22}$ | $\lambda^1_{23}$ | $\lambda^2_{11}$ | $\lambda^2_{12}$ | $\lambda^2_{13}$ | $\lambda^2_{21}$ | $\lambda^2_{22}$ | $\lambda^2_{23}$ |
| | (0.62) | (0.00) | (0.95) | (0.17) | (0.00) | (0.00) | (0.91) | (0.00) | (0.86) | (0.20) | (0.00) | (0.03) |
| HO-BR | 0.0425 | -0.0975 | -0.0062 | -0.004 | 0.1169 | -0.0338 | 0.0381 | -0.097 | -0.0391 | 0.0043 | -0.1262 | 0.001 |
| | (0.00) | (0.00) | (0.39) | (0.70) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.69) | (0.00) | (0.92) |
| HO-RUS | 0.041 | -0.0915 | 0.0074 | -0.0399 | 0.1027 | -0.0141 | 0.057 | -0.0626 | 0.0059 | -0.0177 | -0.113 | 0.0101 |
| | (0.00) | (0.00) | (0.14) | (0.00) | (0.00) | (0.10) | (0.00) | (0.00) | (0.32) | (0.17) | (0.00) | (0.33) |
| HO-IND | | | | | | | | | | | | |
| HO-CH | -0.0434 | 0.2322 | -0.0406 | 0.05 | -0.4188 | 0.1328 | 0.096 | -0.2316 | 0.0156 | -0.0284 | 0.2304 | -0.025 |
| | (0.00) | (0.00) | (0.01) | (0.10) | (0.02) | (0.00) | (0.00) | (0.00) | (0.24) | (0.30) | (0.06) | (0.49) |
| JAP-BR | -0.0082 | 0.4215 | -0.0838 | -0.0433 | 0.241 | 0.0052 | 0.0501 | -0.1138 | -0.0445 | 0.0217 | -0.0249 | 0.0504 |
| | (0.61) | (0.00) | (0.00) | (0.04) | (0.00) | (0.72) | (0.10) | (0.00) | (0.00) | (0.12) | (0.78) | (0.13) |
| JAP-RUS | -0.0115 | 0.1109 | -0.0168 | -0.0323 | 0.2392 | -0.0317 | 0.0175 | -0.0808 | -0.002 | 0.0427 | -0.2769 | 0.0119 |
| | (0.42) | (0.00) | (0.00) | (0.04) | (0.00) | (0.01) | (0.31) | (0.00) | (0.76) | (0.01) | (0.00) | (0.40) |
| JAP-IND | 0.0525 | -0.1749 | 0.0364 | -0.0639 | 0.2719 | -0.0412 | 0.1743 | -0.3812 | -0.0083 | -0.0533 | 0.8097 | -0.1531 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.72) | (0.04) | (0.00) | (0.00) |
| JAP-CH | -0.0277 | 0.1712 | -0.0189 | -0.0563 | 0.3712 | 0.0198 | -0.017 | -0.0656 | -0.0294 | -0.002 | -0.218 | -0.0382 |
| | (0.00) | (0.00) | (0.05) | (0.00) | (0.00) | (0.05) | (0.08) | (0.00) | (0.00) | (0.87) | (0.00) | (0.01) |

$p-$values are given in parenthesis.

In the up market situation, $\lambda^2_{21}$ is positive and significant in all but Russia -India pair while $\lambda^2_{13}$ is found to be negative and significant in all but Brazil-India pair. Finally, in the developed-emerging combination we find that both the coefficients in both down and up markets are mostly significant. There are only few cases where the coefficients are insignificant. In US-Brazil pair, there is no cross spillover (direct) effect from either market on the other in the down market; other than this pair $\lambda^1_{21}$ is insignificant in US-India and Uk-Russia pairs. In case of up market in developed-emerging combination, US-Brazil pair has no such spillover effect from either direction, as in case of down market. The other two cases of insignificant coefficients are: $\lambda^2_{21}$ for US-India and $\lambda^2_{13}$ for Japan-Brazil. As regards the sign of these parameters in this combination, we note that there are a few pairs where the coefficients are negative in both up and down markets. Thus, it is found that taking all the three combinations of markets together the incidence of significance cross (direct) volatility is overwhelmingly present.

As regards the effect of covariance in mean return is concerned, spillovers in developed-developed combination, there are only four cases (for US-UK pair in both directions and for US-Hong Kong, and UK-Japan in one direction only) in down market and three cases (US-Japan, UK-Hong Kong, and UK-Japan in one direction only) in up market, which are insignificant. In case of emerging-emerging combination, the findings are quite is sharp contrast to those of the developed-developed combination. Here in almost all cases in both market movements, the coefficients are insignificant. The only exceptions are $\lambda^1_{12}$ in case of Brazil-Russia pair, $\lambda^1_{22}$ in case of Brazil-India for down market, and $\lambda_{22}^2$ for Russia-India. This shows that there is practically no indirect spillover effect between risk and returns in case of markets in the emerging-emerging combination. As for the developed-emerging combination of markets, the coefficients are found to be insignificant in a number of cases in both market situations. There is no significant spillover effects in both directions for US-Brazil pair as well as UK-China pair in down market. Further, $\lambda_{12}^1$ is insignificant in case of six pairs of markets. In the up market, US-Brazil, UK-China, Hong Kong-Russia and Hong Kong-China have no indirect spillover effects in either direction. It may be recalled that this is same with that of direct spillover effects. Also, $\lambda_{12}^2$ is found to be insignificant in two other pairs (Japan-Russia and Japan-India) while $\lambda_{22}^2$ is insignificant in four pairs (US-India, Hong Kong-Brazil, Japan-Brazil and Japan-China). It may thus be concluded that while the risk of one country (either developed or emerging) affects the returns of another country (either developed or emerging) in terms of indirect spillovers i.e., spillovers through covariance term, this effect is statistically significant for a good number of pairs of markets. It is at the same time true that in some pairs of countries this is statistically insignificant.

*4.2.3. Estimates of the parameters of smoothness, TGARCH and dynamic conditional correlation*

Now looking at the parameters of smoothness i.e., $\gamma_1$ and $\gamma_2$, we find that these two parameters are significant for all pairs in all the three combinations of markets. The parameter values in no combinations of pairs have been found to be either closed to zero or very high. Thus, the validity of consideration of smooth transition in the conditional mean from down market movement to up market movement is empirically established for all the twenty eight bivariate pairs.

Insofar as the behaviour of conditional variance as captured through BTGARCH model is concerned, we note that the parameters in the GARCH component of the model *viz.*, $\alpha_1$, $\alpha_2$, $\beta_1$, and $\beta_2$ are all significant in all the three combinations of markets except for $\alpha_1$ in US-UK, UK-Hong Kong, UK-Brazil and UK-Russia and UK-China, and for $\alpha_2$ in Japan-Brazil pair only. The overwhelming significance of the variance parameters is only expected. Now, looking at $d_1$ and $d_2$, the two coefficients capturing asymmetry (leverage effect) in the conditional variance, we note that this two parameters are highly significant for all the pairs in the three combinations. This establishes that consideration of asymmetry in studying risk-return relationship in bivariate set-up is found to be extremely important in case of DCC approach as well.

Table 4: Parameter estimates of the smoothness, TGARCH and DCC component

| | $\gamma_1$ | $\gamma_2$ | $c_1$ | $c_2$ | $\alpha_1$ | $\alpha_2$ | $d_1$ | $d_2$ | $\beta_1$ | $\beta_2$ | $\varphi_1$ | $\varphi_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Developed-Developed combination** | | | | | | | | | | | | |
| US-UK | 2.491 | 2.1359 | 0.0402 | 0.0748 | 0.006 | 0.0295 | 0.1528 | 0.1053 | 0.8874 | 0.8883 | 0.0294 | 0.8639 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.50) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.06) | (0.00) |
| US-HO | 1.9231 | 1.9054 | 0.0423 | 0.0899 | -0.0224 | 0.0347 | 0.1904 | 0.1321 | 0.8993 | 0.8622 | 0.1909 | 0.2498 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| US-JAP | 2.0027 | 4.0072 | 0.0404 | 0.12 | -0.0246 | 0.0343 | 0.2023 | 0.1501 | 0.8984 | 0.8401 | 0.0027 | 0.2482 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.66) | (0.00) |
| UK-HO | 2.538 | 2.5665 | 0.0398 | 0.076 | 0.0062 | 0.0335 | 0.1508 | 0.1035 | 0.8884 | 0.8853 | 0.0613 | 0.4716 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.45) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-JAP | 2.4612 | 3.4653 | 0.0394 | 0.0967 | 0.0148 | 0.0608 | 0.1521 | 0.0929 | 0.8817 | 0.8584 | 0.0192 | 0.4283 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.05) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.16) | (0.00) |
| HO-JAP | 2.4861 | 3.5528 | 0.1163 | 0.2248 | 0.0399 | 0.0526 | 0.1239 | 0.1294 | 0.8594 | 0.8039 | 0.1598 | 0.4533 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| **Emerging-Emerging combination** | | | | | | | | | | | | |
| BR-RUS | 2.5545 | 2.0747 | 0.1865 | 0.223 | 0.0169 | 0.1054 | 0.1127 | 0.0842 | 0.8808 | 0.8201 | 0.4058 | 0.3285 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.07) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| BR-IND | 2.5934 | 1.9881 | 0.2567 | 0.3074 | 0.0212 | 0.0477 | 0.1186 | 0.2172 | 0.8548 | 0.7569 | 0.3334 | 0.5012 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.02) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| BR-CH | 2.5912 | 2.0114 | 0.2531 | 0.1513 | 0.0195 | 0.0711 | 0.1288 | 0.0429 | 0.8532 | 0.8627 | 0.0736 | 0.2765 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.02) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| RUS-IND | 2.6032 | 2.0995 | 0.2746 | 0.3083 | 0.1105 | 0.0373 | 0.0699 | 0.2323 | 0.8129 | 0.7609 | 0.0511 | 0.3476 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.02) | (0.00) |
| RUS-CH | 2.5946 | 2.1138 | 0.2295 | 0.1403 | 0.1088 | 0.0702 | 0.0811 | 0.0428 | 0.8182 | 0.8671 | -0.0067 | 0.3156 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| IND-CH | 2.4713 | 2.0416 | 0.2984 | 0.2425 | 0.0476 | 0.0893 | 0.2133 | 0.0562 | 0.7624 | 0.811 | 0.1053 | 0.3979 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| **Developed-Emerging combination** | | | | | | | | | | | | |
| US-BR | 2.6187 | 4.3861 | 0.0368 | 0.2057 | -0.015 | 0.0268 | 0.1633 | 0.0999 | 0.9075 | 0.8682 | 0.2894 | 0.4691 |
| | (0.00) | (0.07) | (0.00) | (0.00) | (0.05) | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| US-RUS | 2.2774 | 2.1451 | 0.0384 | 0.2264 | -0.0135 | 0.0965 | 0.1682 | 0.087 | 0.9027 | 0.8244 | 0.1025 | 0.2702 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.07) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.03) | (0.17) |
| US-IND | 12.579 | 11.2284 | 0.0445 | 0.3001 | -0.0125 | 0.0351 | 0.1868 | 0.2296 | 0.8906 | 0.7627 | 0.0203 | 0.582 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.07) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.07) | (0.00) |
| US-CH | - | - | - | - | - | - | - | - | - | - | - | - |
| UK-BR | 2.4707 | 3.4937 | 0.034 | 0.2746 | -0.004 | 0.0309 | 0.1477 | 0.1063 | 0.9046 | 0.8491 | 0.0937 | 0.3693 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.60) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-RUS | 2.5346 | 2.5712 | 0.0366 | 0.2332 | 0.0012 | 0.1099 | 0.1542 | 0.0682 | 0.8947 | 0.821 | 0.0948 | 0.4585 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.86) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-IND | 2.3731 | 3.442 | 0.0396 | 0.316 | 0.0152 | 0.0408 | 0.153 | 0.2162 | 0.8783 | 0.7557 | 0.2476 | 0.3831 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.09) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-CH | 2.4314 | 3.4612 | 0.0394 | 0.1522 | 0.0036 | 0.0689 | 0.1744 | 0.0441 | 0.8819 | 0.8632 | 0.0726 | 0.4279 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.64) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) |
| HO-BR | 5.4707 | 3.4937 | 0.0873 | 0.3288 | 0.0281 | 0.0304 | 0.1342 | 0.1225 | 0.8736 | 0.8294 | 0.1752 | 0.4645 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| HO-RUS | 2.4851 | 3.503 | 0.0758 | 0.2312 | 0.0231 | 0.1117 | 0.1186 | 0.0668 | 0.8914 | 0.8236 | -0.0215 | 0.4762 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.02) | (0.00) |
| HO-IND | - | - | - | - | - | - | - | - | - | - | - | - |
| HO-CH | 2.4485 | 3.4955 | 0.077 | 0.1559 | 0.0223 | 0.067 | 0.1267 | 0.0517 | 0.8862 | 0.8608 | 0.2992 | 0.0393 |

*continued on next page*

Table: 4 continued from previous page

| | $\gamma_1$ | $\gamma_2$ | $c_1$ | $c_2$ | $\alpha_1$ | $\alpha_2$ | $d_1$ | $d_2$ | $\beta_1$ | $\beta_2$ | $\varphi_1$ | $\varphi_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.55) |
| JAP-BR | 2.4811 | 3.4648 | 0.1117 | 0.3188 | 0.0333 | 0.0137 | 0.1409 | 0.157 | 0.8537 | 0.8307 | 0.122 | 0.3606 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.12) | (0.00) | (0.00) | (0.00) | (0.00) | (0.13) | (0.00) |
| JAP-RUS | 2.4809 | 3.4603 | 0.1171 | 0.2404 | 0.0292 | 0.1125 | 0.1344 | 0.0687 | 0.8607 | 0.8206 | -0.0117 | 0.3687 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.04) | (0.00) |
| JAP-IND | 2.6883 | 3.2436 | 0.1323 | 0.3548 | 0.0494 | 0.0344 | 0.0985 | 0.244 | 0.8513 | 0.7428 | 0.1615 | 0.6733 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| JAP-CH | 2.5487 | 3.5357 | 0.1294 | 0.1674 | 0.0308 | 0.0698 | 0.1444 | 0.0484 | 0.8494 | 0.8561 | 0.082 | 0.4417 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |

$p-$values are given in parenthesis.

As regards the conditional correlations across any two of these markets, we find that the parameters, $\varphi_1$ and $\varphi_2$, are both significant for all pairs of stock markets except for US-Japan, UK-Japan and Japan-Brazil, and US-Russia where one of these two parameters is insignificant. Thus, we can conclude that the DCC modelling approach, on the whole, has been found to be useful in explaining the volatility dynamics involving the stock markets of these countries.

### *4.3. Findings on statistical tests*

In this section we report the results of several tests of hypotheses of interest concerning the asymmetric nature of the spillover in down and up markets and the dynamic nature of the conditional correlation in MGARCH model and the appropriateness of consideration of leverage effect in the volatility specification. To that end, we first reports the results of the Wald test for different null hypotheses mentioned in Section 3.

#### *4.3.1. Results of the Wald test*

The Wald test statistic values for different null hypotheses on the different spillovers from one stock market to another in up and down market situations are presented in Table 5. The results of the Wald test on the presence of dynamic conditional correlation are also given in the table.

*Tests of spillovers in conditional mean in the two market conditions*

Looking at the first two columns of Table 5, we find that in most cases the null hypothesis of no spillover in mean from ane stock market to another in both up and down market is rejected. In particular, among the developed economics, expected returns of the UK, Hong Kong and Japan affect the expected returns of the US and also of Japan on Hong Kong at least in one market condition. But Hong Kong and Japan have no such effect to UK. On the other hand, the spillover effects from the US to the UK, Hong Kong and Japan, from the UK to Hong Kong and Japan, and Hong Kong to Japan are statistically significant. As regards the asymmetry in effects in the up and down markets are concerned, columns 4 and 5 of Table 5 show that effects from the UK, Hong Kong and Japan to the US, Hong Kong to the UK and Japan to Hong Kong have significant differences in up and down markets. Further, the effect is different in the two market conditions in the other direction only in case of the US to Hong Kong, the UK to Japan, and Hong Kong to Japan.

In the case, for the emerging economies, the bidirectional spillovers are present in Brazil-Russia, Russia-India, Russia-China and India-China combination and that is at least in one market situation. The spillover effects of change in past returns are absent from Brazil to China and India. Whereas the spillover in the other direction for the above mentioned countries are present. This results shows that, among the BRIC groups, stock markets of China and India are not influenced by the stock market of Brazil. Looking at the null hypothesis of $b_{12}^1 = b_{12}^2$ and $b_{21}^1 = b_{21}^2$, for the emerging group, we find that the asymmetric spillover is present in both directions in case of Russia-China and India-China. For other combinations, Brazil and India have different spillover effects from Russia, and similarly Chinese stock market has different impacts on the stock market of Brazil in both up and down markets.

Among the pairs of developed-emerging combination, the UK and Russia pair have no spillover effect of one return on the other in any direction – both in up and down market conditions. Among the other pairs, there is significant spillover in at least one of up and down market conditions in both the directions for the US-Brazil, the US-India, the UK-Brazil, Hong-Kong-Brazil, Japan-Brazil, Japan-India and Japan-China pairs. Among the rest, stock returns on the US, the UK and Hong Kong influence the return on Russia, India & China, and Brazil & China respectively, in at least one market condition. The spillover effects from Brazil and India to the US and from China to the UK and Hong Kong are dependent on the market condition. We also find that the spillover effects from the US to Russia and India, the UK to Brazil and China, Hong Kong to Brazil and China and Japan to Brazil, Russia and China have significant differences in the two market conditions.

*Asymmetry in volatility-in-mean component*

In columns 6 through 10 of Table 5 we report the results of the test of differences between the effects of volatility-in-mean in up and down market conditions. Columns 6 and 9 report the risk-return relationship of the same market. Whereas, columns 7 and 8 report the effect on return of volatility of other market in difference market situation. Here we find that, in the combination of developed countries, there exists at least one asymmetric relation in risk-return in case of the US-Hong Kong, the UK-Hong Kong, the UK-Japan, and the Hong Kong-Japan combinations. Among the stock markets of emerging economies, all the pairs have asymmetric relationship for at least one direction of the relationship. In case of the combination of developed-emerging economies, except the UK-Brazil, the US-India and Japan-Brazil, all other pairs have asymmetric risk-return relationship in at least for one direction. But in case of the null hypothesis specified in column 10 of Table 5, where we consider all the 'in-mean' components to have the same effect for both the market conditions, on return, the null hypothesis of equal effect is rejected at 1% level for all the combinations.

Table 5: Results of the Wald test on equality of coefficients for up and down markets

| | $b^1_{12} = b^2_{12} = 0$ | $b^1_{21} = b^2_{21} = 0$ | $b^1_{12} = b^2_{12}$ | $b^1_{21} = b^2_{21}$ | $\lambda^1_{11} = \lambda^2_{11}$ | $\lambda^1_{13} = \lambda^2_{13}$ | $\lambda^1_{21} = \lambda^2_{21}$ | $\lambda^1_{23} = \lambda^2_{23}$ | $\lambda^1_{ij} = \lambda^2_{ij}$ | $d_1 = d_2 = 0$ | $\phi_1 = \phi_2 = 0$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| **Developed-Developed combination** | | | | | | | | | | | |
| US-UK | 50.753 | 717.284 | 45.541 | 0.004 | 0.405 | 3.544 | 2.476 | 0.003 | 188.585 | 233.223 | 350.767 |
| | (0.00) | (0.00) | (0.00) | (0.95) | (0.52) | (0.06) | (0.12) | (0.95) | (0.00) | (0.00) | (0.00) |
| US-HO | 54.202 | 664.715 | 50.124 | 45.737 | 0.061 | 11.347 | 16.548 | 13.412 | 154.544 | 242.574 | 263.858 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.80) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| US-JAP | 9.160 | 930.559 | 8.778 | 2.190 | 0.293 | 6.743 | 3.403 | 0.989 | 269.066 | 294.116 | 518.575 |
| | (0.01) | (0.00) | (0.00) | (0.14) | (0.59) | (0.01) | (0.07) | (0.32) | (0.00) | (0.00) | (0.00) |
| UK-HO | 4.268 | 494.513 | 4.241 | 1.062 | 0.020 | 2.644 | 10.985 | 14.609 | 342.280 | 186.955 | 113.952 |
| | (0.12) | (0.00) | (0.04) | (0.30) | (0.89) | (0.10) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-JAP | 1.735 | 373.629 | 1.710 | 5.945 | 8.053 | 0.306 | 0.394 | 0.647 | 255.834 | 227.424 | 640.079 |
| | (0.42) | (0.00) | (0.19) | (0.01) | (0.00) | (0.58) | (0.53) | (0.42) | (0.00) | (0.00) | (0.00) |
| HO-JAP | 61.016 | 8.051 | 60.894 | 6.012 | 38.952 | 4.944 | 43.281 | 61.428 | 405.023 | 326.265 | 2124.909 |
| | (0.00) | (0.02) | (0.00) | (0.01) | (0.00) | (0.03) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| **Emerging-Emerging combination** | | | | | | | | | | | |
| BR-RUS | 5.872 | 99.615 | 1.239 | 12.106 | 45.795 | 2.036 | 0.066 | 1.736 | 111.920 | 48.821 | 1210.474 |
| | (0.05) | (0.00) | (0.27) | (0.00) | (0.00) | (0.15) | (0.80) | (0.19) | (0.00) | (0.00) | (0.00) |
| BR-IND | 1.154 | 61.726 | 0.133 | 1.515 | 4.571 | 1.414 | 0.152 | 0.936 | 64.412 | 153.444 | 204.697 |
| | (0.56) | (0.00) | (0.71) | (0.22) | (0.03) | (0.23) | (0.70) | (0.33) | (0.00) | (0.00) | (0.00) |
| BR-CH | 1.352 | 55.303 | 0.254 | 14.376 | 7.180 | 0.302 | 0.552 | 1.416 | 159.481 | 127.381 | 812.625 |
| | (0.51) | (0.00) | (0.61) | (0.00) | (0.01) | (0.58) | (0.46) | (0.23) | (0.00) | (0.00) | (0.00) |
| RUS-IND | 5.720 | 81.945 | 4.308 | 1.600 | 6.921 | 0.149 | 7.030 | 1.637 | 44.997 | 204.578 | 514.375 |
| | (0.06) | (0.00) | (0.04) | (0.21) | (0.01) | (0.70) | (0.01) | (0.20) | (0.00) | (0.00) | (0.00) |
| RUS-CH | 11.599 | 40.937 | 2.832 | 6.497 | 13.551 | 0.054 | 0.365 | 4.615 | 131.614 | 47.424 | 1390.465 |

*continued on next page*

Table: 5 continued from previous page

| | $b^1_{12} = b^2_{12} = 0$ | $b^1_{21} = b^2_{21} = 0$ | $b^1_{12} = b^2_{12}$ | $b^1_{21} = b^2_{21}$ | $\lambda^1_{11} = \lambda^2_{11}$ | $\lambda^1_{13} = \lambda^2_{13}$ | $\lambda^1_{21} = \lambda^2_{21}$ | $\lambda^1_{23} = \lambda^2_{23}$ | $\lambda^1_{ij} = \lambda^2_{ij}$ | $d_1 = d_2 = 0$ | $\phi_1 = \phi_2 = 0$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | (0.00) | (0.00) | (0.09) | (0.01) | (0.00) | (0.82) | (0.55) | (0.03) | (0.00) | (0.00) | (0.00) |
| IND-CH | 6.379 | 14.498 | 6.104 | 2.870 | 0.074 | 0.716 | 2.263 | 7.080 | 127.138 | 347.872 | 2116.995 |
| | (0.04) | (0.00) | (0.01) | (0.09) | (0.79) | (0.40) | (0.13) | (0.01) | (0.00) | (0.00) | (0.00) |
| **Developed-Emerging combination** | | | | | | | | | | | |
| US-BR | 10.410 | 6.975 | 10.201 | 1.958 | 0.026 | 0.169 | 0.670 | 0.024 | 8.510 | 117.228 | 209.049 |
| | (0.01) | (0.03) | (0.00) | (0.16) | (0.87) | (0.68) | (0.41) | (0.88) | (0.20) | (0.00) | (0.00) |
| US-RUS | 1.714 | 62.571 | 1.530 | 0.000 | 18.497 | 2.827 | 14.801 | 13.265 | 26.385 | 102.413 | 9.188 |
| | (0.42) | (0.00) | (0.22) | (0.99) | (0.00) | (0.09) | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) |
| US-IND | 8.336 | 610.383 | 6.227 | 6.115 | 0.028 | 6.105 | 5.559 | 1.637 | 49.925 | 317.166 | 2367.885 |
| | (0.02) | (0.00) | (0.01) | (0.01) | (0.87) | (0.01) | (0.02) | (0.20) | (0.00) | (0.00) | (0.00) |
| US-CH | | | | | | | | | | | |
| UK-BR | 66.796 | 121.373 | 0.003 | 64.714 | 0.512 | 2.482 | 266.486 | 9.494 | 2117.721 | 333.029 | 1366.624 |
| | (0.00) | (0.00) | (0.96) | (0.00) | (0.47) | (0.12) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| UK-RUS | 3.636 | 2.554 | 0.955 | 2.058 | 10.906 | 0.250 | 25.638 | 3.404 | 463.628 | 140.853 | 159.767 |
| | (0.16) | (0.28) | (0.33) | (0.15) | (0.00) | (0.62) | (0.00) | (0.07) | (0.00) | (0.00) | (0.00) |
| UK-IND | 0.784 | 85.217 | 0.655 | 0.060 | 10.277 | 30.243 | 0.031 | 3.982 | 42.523 | 252.415 | 249.256 |
| | (0.68) | (0.00) | (0.42) | (0.81) | (0.00) | (0.00) | (0.86) | (0.05) | (0.00) | (0.00) | (0.00) |
| UK-CH | 4.280 | 197.604 | 4.264 | 29.956 | 0.113 | 0.023 | 3.564 | 2.939 | 659.310 | 170.939 | 1629.927 |
| | (0.12) | (0.00) | (0.04) | (0.00) | (0.74) | (0.88) | (0.06) | (0.09) | (0.00) | (0.00) | (0.00) |
| HO-BR | 376.326 | 31.797 | 0.896 | 30.259 | 0.084 | 8.118 | 0.371 | 7.094 | 338.475 | 397.098 | 2692.377 |
| | (0.00) | (0.00) | (0.34) | (0.00) | (0.77) | (0.00) | (0.54) | (0.01) | (0.00) | (0.00) | (0.00) |
| HO-RUS | 66.733 | 0.824 | 0.452 | 0.824 | 1.260 | 0.038 | 2.017 | 3.446 | 201.454 | 212.817 | 2155.608 |
| | (0.00) | (0.66) | (0.50) | (0.36) | (0.26) | (0.85) | (0.16) | (0.06) | (0.00) | (0.00) | (0.00) |
| HO-IND | | | | | | | | | | | |
| HO-CH | 1.192 | 10.532 | 0.670 | 6.965 | 19.042 | 6.659 | 2.098 | 5.963 | 379.982 | 67.314 | 20.817 |
| | (0.55) | (0.01) | (0.41) | (0.01) | (0.00) | (0.01) | (0.15) | (0.01) | (0.00) | (0.00) | (0.00) |
| JAP-BR | 302.162 | 7.744 | 9.158 | 7.624 | 2.169 | 3.332 | 5.617 | 1.481 | 1723.050 | 222.544 | 1305.991 |
| | (0.00) | (0.02) | (0.00) | (0.01) | (0.14) | (0.07) | (0.02) | (0.22) | (0.00) | (0.00) | (0.00) |
| JAP-RUS | 166.609 | 0.973 | 2.205 | 0.856 | 2.652 | 3.117 | 7.441 | 5.024 | 140.085 | 180.027 | 1366.755 |
| | (0.00) | (0.61) | (0.14) | (0.35) | (0.10) | (0.08) | (0.01) | (0.03) | (0.00) | (0.00) | (0.00) |
| JAP-IND | 38.747 | 39.796 | 0.011 | 6.639 | 7.599 | 3.311 | 0.162 | 11.555 | 48.465 | 215.545 | 805.809 |
| | (0.00) | (0.00) | (0.92) | (0.01) | (0.01) | (0.07) | (0.69) | (0.00) | (0.00) | (0.00) | (0.00) |
| JAP-CH | 16.803 | 35.266 | 1.302 | 17.526 | 0.622 | 0.749 | 11.474 | 12.790 | 1850.685 | 113.906 | 1924.246 |
| | (0.00) | (0.00) | (0.25) | (0.00) | (0.43) | (0.39) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |

$p-$values are given in parenthesis. In column 10 of this table $i = 1, 2, 3$; $j = 1, 2$.

These results strongly support the asymmetric nature of risk-return behaviour in a bivariate set-up. In columns 7 and 8 we have reported the Wald test results of the null hypotheses $\lambda^1_{13} = \lambda^2_{13}$ and $\lambda^1_{21} = \lambda^2_{21}$, i.e., effects of risk from one market to another in up and down market conditions are equal and find that among the developed countries except the UK and Japan pair, the null hypothesis is rejected. But in case of emerging markets except the effect of risk of stock market of Russia to India's stock return, the null hypothesis cannot be rejected. In Table 3 we have also found the poor volatility-return relation among the emerging economies in both market situations. Among the developed and emerging economies combinations, except the US-Brazil, and Hong

Kong-Russia pairs, all other pairs have asymmetric effects of volatility in up and down markets at least in one direction.

*Leverage effects and Time varying conditional correlation*

In the last two columns of Table 5 we report the testing results of the null hypothesis of no leverage effect and no dynamic behaviour in the conditional correlation. Here the testing results reject both the null hypotheses for all the pairs irrespective of the development status of the economy.

## 5. Conclusions

In this paper, we have examined the transmission of stock return and volatility among different pairs of countries from four developed and four emerging economies. For this purpose, we have used a bivariate GARCH-in-mean model with smooth transition behaviour in conditional mean which captures the asymmetric nature of spillover in two different market conditions. For the bivariate GARCH model, we have followed the dynamic conditional correlation approach with due consideration to asymmetry due to leverage effect so that the asymmetric nature of spillover of returns and risk associated with one stock market to another can be studied.

Our results suggest that asymmetric volatility is common in all the return series, and the conditional correlation of the shocks of stock returns are highly time varying in nature. Insofar as the mean spillover among the developed stock market are concerned, we have seen that there is significant effect of return of one market to another but the sign of this effect varies over pairs of countries concerned and market conditions as well. Among the emerging markets, spillover effects are positive and significant for some pairs in both the market conditions with the exception of China. In case of China the spillover effect from China to any other market is negative wherever significant. But in case of developed-emerging combinations, the spillover effect is positive in up market in all such pairs except the spillover from China to Japan. In the down market condition, there is a mixed result depending on the combination concerned.

The results of volatility-in-mean effect from one market to another is found to be mostly negative, and this effect is significant among developed-developed and developed-emerging market combinations but almost insignificant among pairs of emerging market combination. Finally, we have also found strong evidence of asymmetric nature in the spillover effects among all the combinations in up and down market conditions.

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