INTERNATIONAL LINKAGE OF RUSSIAN MARKET AND RUSSIAN FINANCIAL CRISIS: A MULTIVARIATE GARCH ANALYSIS

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Very preliminary draft - Comments are welcome

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Abstract

The purpose of this study is two fold. First we look at the international linkage of Russian equity market and second we examine the international transmission of the 1998 Russian financial crisis. We estimate a bivariate GARCH-BEKK model proposed by Engle and Kroner (1995). Four pair-wise models are estimated for Russia with USA, European Union, Emerging Europe and Asia by using daily total return indices. We find evidence of direct linkage between Russian equity market, both in regards of returns and volatility, with all other markets. However the linkage is week, indicating partial integration of Russian market into the world market. While analyzing the contagion effects of Russian Financial crisis 1998, three subsets are examined, pre crisis (1994-1998), during crisis (Aug.1998-Dec.1998) and post crisis (1999-2007).Volatility spillovers are found in all cases, though the dynamics of the conditional volatilities differ. USA and Emerging Europe exhibit bidirectional while European Union and Asia display unidirectional linkage in pre crisis sample. Whereas, after the crisis period shows bidirectional connection with USA and Asia while unidirectional ties with Emerging Europe. Surprisingly, no statistically significant relations were found between Russian equity market and the equity markets of European Union in post crisis sample. Finally, highly significant but negative shocks and volatility spillovers were observed from Russia to all other markets during the crisis period, indicating clear evidences of crisis contagion.

JEL-classification: C32, G15

Keywords: multivariate GARCH, Volatility spillovers, Russian Financial crisis

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1 INTRODUCTION

Past decade has witnessed a series of financial and economic crises, affecting both developed and developing economies. One of the common concerns of financial analysts and market participants, during these periods, has been the correlation among countries and financial markets, and the likelihood that a crisis will spill over resulting in an intense volatility somewhere else in the world's financial markets.[1] Although there is no general consensus about the contagion effects of all these crises, however, they seem to differ across crises and countries. For instance, financial turbulence in Turkish stock market in 2001 appeared to be isolated with no affect anywhere else in the world (see, e.g., Desai, 2003). On the other hand, some recent financial crises, e.g., the Mexican and Asian crises appeared to be regional specific (see, e.g., Glick and Rose, 1999). In contrast to others the Russian crisis of 1998, characterized by increased volatility in global securities markets has been considered as the worst crisis in recent times (see, e.g., Bank for International Settlements, 1999).

The transmission of Russian crisis was quick and worldwide. For example, the influences were felt after only a couple of weeks in the United States where Russian crisis almost destroyed the hedge fund Long-Term Capital Management (see, e.g., Masson, 2001). At the same time, emerging markets of Central Asia and Eastern Europe observed severe contagion effects mainly due to the massive devaluation of Russian Rubel and the following debt default, which ultimately increased the emerging market risk and decreased the commodity exports from these emerging markets to Russia (see, e.g., Dungey et al., 2006). Moreover, during the crisis period shocks were observed in countries with little in common in regards of the traditional definition of contagion effects.[2] For example, Baig and Goldfajn (2001) argue that the Russian crisis precipitated the Brazilian crisis.

There are several studies focusing on the stock market linkage across countries. However, the bulk of research studies the return and volatility linkages between developed markets. For instance, Hamao et al. (1990), Lin et al. (1994), Susmel and Engle (1994), Karolyi (1995) and Theodossiou and Lee (1993) are among those who investigated the linkage between developed markets, such as USA, UK, Canada, Germany and Japan. All these studies confirm clear relationship between each other. There exist some papers who explore the relationship between emerging markets of different regions as well though the work is still very scare, e.g., Worthington et al. (2001) look at price linkages in Asian emerging markets, Kasch-Haroutounian and Price (2001) examine the emerging markets of Central Europe, Sola et al. (2002) analyze volatility links between the stock markets of Thailand, South Korea and Brazil while more recently Li and Majerowska (2007) study the linkage between the emerging markets of Eastern European. Similarly, only a few papers have investigated the interrelationship between developed and emerging markets. In most studies the benchmark developed markets are USA, Western Europe and Japan and emerging markets includes Pacific-Basin markets, East Asian markets, Latin American financial markets and Eastern Europe. Examples include, Liu and Pan (1997), Liu et al. (1998), Cheung et al. (2002) and Walti (2003). Surprisingly, Russian financial market could not attract the attention of financial researchers despite of its diverse nature and potential for future investors as it should.

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1 Prior research has documented a high correlation between countries and financial markets during the crisis periods (see, e.g., Chesnay and Jondeau, 2001)

2 See, for example, Lowell et al. (1998), Goldstein (1998) for taxonomies of contagion.

On the other hand, when it comes to the contagion effects of financial crises from one market to others, only Asian crisis has been examined thoroughly (see, e.g., Sander and Kleimeier, 2003; Jackson, 1999; Rakshit, 2002; Park and Song, 2001), there exist a sizeable amount of research analyzing Latin American financial crashes as well (see, e.g., Rojas-Suarez and Weisbrod, 1995; Bazdresch and Werner, 2001; Cardoso and Hedwege, 2001; Corbacho et al, 2003). However, Russian crisis still need more empirical investigation. Only few attempts have been made to explore the contagion effects of Russian crisis, studies representing Russian crisis directly are limited, Empirical studies that cover the Russian crisis to some extent are Brüggemann and Linne(1999), Bussiere and Mulder (1999), Caramazza et al. (2000), Cartapanis et al. (1999), Feridun (2004), Gelos and Sahay (2001) and Baig and Goldfajn (2001). At the same time, there is a difference of opinion on the contagion effects of Russian turmoil, For instance, Gelos and Sahay (2001) found no evidence of contagion. Meanwhile, using firm-level information, Forbes (2000) found evidence of contagion after the Russian crisis. However, some very recent studies raised the importance of this concern (contagion) by combing the Russian and LTCM crises of 1998 in international bond markets and global equity markets (see, e.g., Dungey et al., 2006, 2007). Using multi-regime factor model of equity and bond markets, they found clear evidence of contagion effects from Russia, to both emerging and developed countries.

Nevertheless, our emphasis is strictly on Russian crisis 1998. We take a GARCH modelling approach. Specifically, we estimate a bivariate GARCH model, for which a BEKK representation is adopted. This approach has been widely used in studying the international linkage of different markets and interdependence of one market to other during all the episodes of crises mentioned earlier, however, as per authors knowledge, it has never been utilized in case of Russian crisis, or at least as used in this study.

In the present study we examine the transmission of the Russian crisis across global financial markets, both developed and emerging, particularly, the United States, the European Union, financial markets of Emerging Europe and Asia. This particular set of regions is of special interest since after the brake up of USSR all these regions have played an important role in Russian economy as a trade partners and vice versa. For example, in early 1990's United States recognized Russia as most-favored-nation to make it easier for Americans to do business in Russia and today Russia is one of the favourite investment for US investors. For Europe, Russian economy has always been important. Today Russia is EU's fifth largest trading partner while EU is absorbing half of Russia's foreign trade. Eastern Europe has traditionally strong economic links with Russia in business and trade. Finally, Asia has become the centre of attention for Russian policy makers considering the rapid growth in the region, e.g., in India and China.

Basically we address two issues. First we look at the international linkage of modern Russian equity market and second we examine the international transmission of the 1998 Russian financial crisis. Four pair-wise models are estimated for Russia with USA, European Union, Emerging Europe and Asia by using daily total return indices. We find evidence of direct linkage between Russian equity market, both in regards of returns and volatility, with all other markets. However the linkage is week, indicating partial integration of Russian market into world market as suggested by Saleem and Vaihekoski (2007). While analyzing the contagion effect of Russian Financial crisis 1998, three subsets are examined, pre crisis (1994-1998), during crisis (Aug.1998 – Dec.1998) and post crisis (1999-2007). Volatility spillovers are found in all cases. Though, the dynamics of the conditional volatilities differ. USA and Emerging Europe exhibit bidirectional while European Union and Asia display unidirectional linkage in pre crisis sample. Whereas, after the crisis period shows bidirectional connection with USA and Asia while unidirectional ties with Emerging Europe. Surprisingly, no statistically significant relations were found between Russian equity market and the equity markets of European Union in post crisis sample. Finally, highly significant but negative shocks and volatility spillovers were observed from Russia to all other markets during the crisis period, indicating clear evidences of crisis contagion.

Thus, within the context of the Russian financial crisis, it is very clear that a better understanding of the nature of international interdependence during crisis periods is inevitable for the international investors, multinational corporations and portfolio managers, who all are involved in minimizing and managing their financial risk exposure. Similarly, international transmission of stock market volatility can impact on corporate capital budgeting decisions, investors' consumption decisions, and other business cycle variables.

The plan of the paper is as follows. The next section describes the bivariate GARCH model used to study the return and volatility spillovers among stock markets. Section 3 presents the data in this study. Section 4 shows the empirical results. Section 5 concludes.

2 MODEL SPECIFICATION

The Autogressive Conditional Heteroscedasticity (ARCH) process proposed by Engle (1982) and generalised ARCH (GARCH) by Bollerslev (1986) are well known for volatility modelling of stock returns. However, in examining volatility linkages between countries, a multivariate GARCH approach is warranted over univariate setting. Such models can only be estimated by imposing some specific restrictions on the conditional variance-covariance matrix, for example, positive definiteness which helps to simplify the optimization process. Among others Bollerslev et al. (1988) proposed a model in early days to check the volatility linkage between countries, however, the model was not able to assure the positive definiteness of the conditional variance matrix. Moreover, this approach does not allow the cross equation conditional variances and covariances to affect each other due to oversimplifying restrictions. Many of these problems are circumvented by the BEKK (Baba, Engle, Kraft and Kroner) parameterization proposed by Engle and Kroner (1995) uses quadratic forms to ensure positive definiteness. Their model confers with the hypothesis of constant correlation and permits for volatility spillover across markets. There is, however, a trade-off between its generality and the computational difficulties growing with higher dimensional systems.

We start our empirical specification with the following bivariate GARCH model[3] which accommodates each market's own returns and the returns of other markets lagged one period.

(1) $$r_t = \alpha + \beta r_{t-1} + u_t$$

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

where rt is an $n \times 1$ vector of daily returns at time t for each market. The $n \times 1$ vector of random errors, μt represents the innovation for each market at time t with its corresponding $n \times n$

3 The model is based on the bivariate GARCH (1, 1)-BEKK representation proposed by Engle and Kroner (1995).

conditional variance-covariance matrix, ***Ht***. The market information available at time *t-1* is represented by the information set *Ωt-1*.The $n\times 1$ vector, α, represent long-term drift coefficients. The own market mean spillovers and cross market mean spillovers can be measured by the estimates of the elements of the matrix β. This multivariate structure then facilitates the measurement of the effects of the innovations in the mean stock returns of one series on its own lagged returns and those of the lagged returns of other markets.

Given the above expression, and following Engle and Kroner (1995) the conditional covariance matrix can be stated as follows:

(3) $$H_t = C_0'C_0 + A_{11}'\varepsilon_{t-1}\varepsilon_{t-1}'A_{11} + G_{11}'H_{t-1}G_{11}$$

where the parameter matrices for the variance equation are defined as $\boldsymbol{C_0}$, which is restricted to be lower triangular and two unrestricted matrices $\boldsymbol{A_{11}}$ and $\boldsymbol{G_{11}}$. Therefore the second moment can be represented by:

(4) $$H_t = C_0'C_0 + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1},\varepsilon_{2,t-1} \\ \varepsilon_{1,t-1},\varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}' H_{t-1} \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}$$

The equation (4) for $\boldsymbol{H_t}$ can be further expanded by matrix multiplication and it takes the following form:

(5) $$h_{11,t} = c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}^2\varepsilon_{2,t-1}^2 + g_{11}^2h_{11,t-1} + 2g_{11}g_{21}h_{12,t-1} + g_{21}^2h_{22,t-1}$$

(6) $$\begin{aligned} h_{12,t} = {} & c_{11}c_{21} + a_{11}a_{12}\varepsilon_{1,t-1}^2 + (a_{21}a_{12} + a_{11}a_{22})\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}a_{22}\varepsilon_{2,t-1}^2 + g_{11}g_{12}h_{11,t-1} \\ & + (g_{21}g_{12} + g_{11}g_{22})h_{12,t-1} + g_{21}g_{22}h_{22,t-1} \end{aligned}$$

(7) $$h_{22,t} = c_{21}^2 + c_{22}^2 + a_{12}^2\varepsilon_{1,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{22}^2\varepsilon_{2,t-1}^2 + g_{12}^2h_{11,t-1} + 2g_{12}g_{22}h_{12,t-1} + g_{22}^2h_{22,t-1}$$

First, either off diagonal terms of the matrix $\boldsymbol{A_{11}}$ and $\boldsymbol{G_{11}}$ are restricted to be zero so that the lagged squared residuals and lagged conditional variance of returns do not enter the variance equation of returns as an explanatory variable. To test any causality effect from one to other, a_{12} and g_{12} are set to zero. The variance and covariance equations will take the following form.

(8) $$h_{11,t} = c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}^2\varepsilon_{2,t-1}^2 + g_{11}^2h_{11,t-1} + 2g_{11}g_{21}h_{12,t-1} + g_{21}^2h_{22,t-1}$$

(9) $$h_{12,t} = c_{11}c_{21} + a_{11}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}a_{22}\varepsilon_{2,t-1}^2 + g_{11}g_{22}h_{12,t-1} + g_{21}g_{22}h_{22,t-1}$$

(10) $$h_{22,t} = c_{21}^2 + c_{22}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + g_{22}^2h_{22,t-1}$$

On the other hand, a_{21} and g_{21} are set equal to zero when we test the causality effect from one to other. All the maximum likelihood estimations are optimized by the Berndt, Hall, Hall and

Hausmann (BHHH)[4] algorithm. From equations (5) to (10), the conditional log likelihood function L(θ) for a sample of T observations has the following form:

$$L(\theta) = \sum_{t=1}^{T} l_t(\theta) \tag{11}$$

$$l_t(\theta) = -\log 2\pi - 1/2 \log\left|H_t(\theta)\right| - 1/2 \varepsilon_t^{'}(\theta) H_t^{-1}(\theta) \varepsilon_t(\theta), \tag{12}$$

where, θ denotes the vector of all the unknown parameters. Numerical maximization of equation (11) and (12) yields the maximum likelihood estimates with asymptotic standard errors.

Finally, to test the null hypothesis that the model is correctly specified, or equivalently, that the noise terms, μt, are random the Ljung-Box Q statistic is used which is assumed to be asymptotically distributed as χ2 with (p - k) degrees of freedom where k is the number of explanatory variables.

3 DATA AND PRELIMENARY STATISTICS

The data comprise daily total return indices calculated by Datastream for the Russia, European Union, Emerging Europe, Asia and US markets. The dataset starts from January 1995 and ends at June 2007, yielding 3247 observations in total for each series. The DataStream EMU (European Monetary Union) Index, DataStream EM (Emerging Europe) Index and DataStream Asia Index are free float-adjusted market capitalization indexes that are designed to measure equity market performance within EMU, Emerging Europe and Asia, while return indices for Russia and USA are national indices calculated by DataStream. The beginning of our data set is due to the availability of total return index for Russia and the use daily data (5 days) in this study is to get meaningful statistical generalizations and to obtain a better picture of the movements of market return.

We use full sample to examine the international linkage of Russian market, while analyzing the contagion effects of Russian financial crisis we divide our data set in to three subsets, pre-crisis (Jan. 1995- July 1998), during crisis (August 1998-December 1998) and post crisis period (Jan. 1999-Jun. 2007).

Daily returns are constructed as the first difference of logarithmic prices multiplied by 100. Table 1 presents a wide range of descriptive statistics for the five series under investigation, for the full sample and for three sub-periods. As a first step, Stationarity in the time series is checked by applying the Augmented Dickey Fuller (ADF) test. The results (see Table 1) allow us to reject the null hypothesis that returns have unit root in favor of alternate hypothesis of stationarity (even at 1% MacKinnon critical value). The development of equity market indices is shown in Figure 1. This clearly exhibits non-stationarity.

The first two moments of the data, i.e., mean and standard deviation, are multiplied by 240 and the square root of 240 to show them in annual terms. As one can anticipate, both emerging regions Russia and emerging Europe have highest returns as compared to the developed regions (USA and EMU) however the high returns are clearly associated with high

4 Marquardt maximum likelihood has also been applied, however, BHHH algorithm is found to have better performance.

risks (standard deviations). Asia is offering the lowest returns (3.632) during the period under investigation with relatively higher standard deviation (17.575 %).

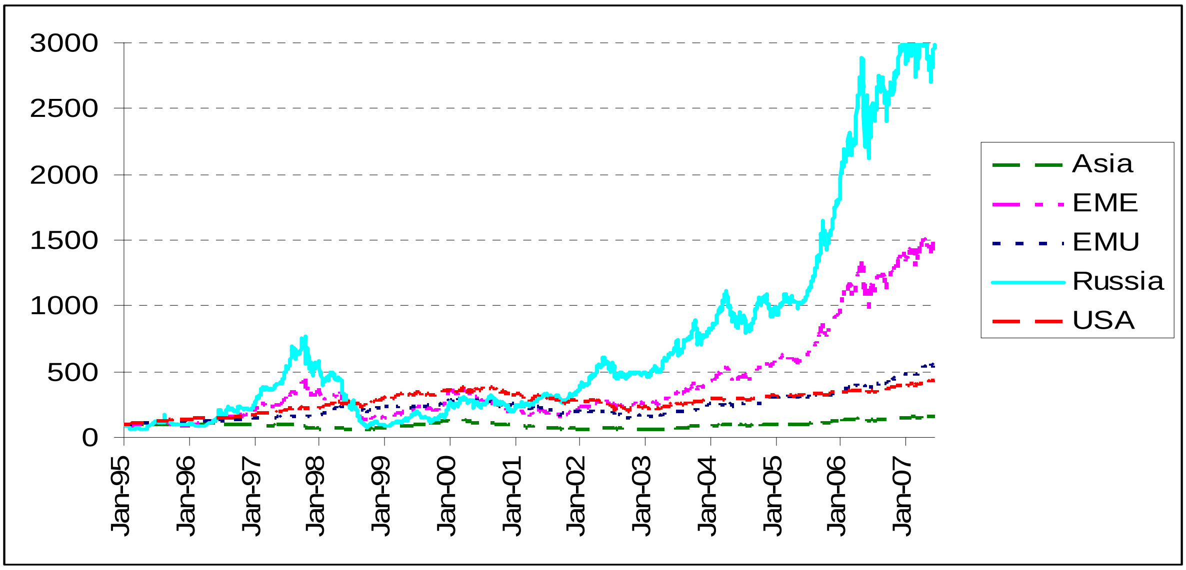

Figure 1. Development of Asian, Emerging Europe, European Union, US and Russian equity market indices in USD terms from 1995 to 2007. Indices are scaled to start from 100.

Interesting shift of returns from high to low were found in case of developed markets and opposite for emerging markets while analysing pre and post crisis period. The crisis period exhibit a very extra ordinary period for all markets, high negative returns were found in emerging world (-165.187 for Russia and -91.972 for emerging Europe). All the return series are, without exception, highly leptokurtic and exhibit strong skewness, mostly to the left. This suggests the presence of asymmetry towards negative values. To check the null hypothesis of normal distribution we calculate Jarque-Bera test statistic (p-values reported) which rejects the null of the normality in all cases.

Since we use GARCH process to model the variance in the asset returns, we also test for the presence of the ARCH effect. Table 1 reports p-values for the Ljung-Box test statistic on the squared returns (24 lags) together with the ARCH LM-statistic (five lags) on each returns series. The results show evidence of autocorrelation pattern in both residuals and their squares, which suggest that GARCH parameterization might be appropriate for the conditional variance processes.

Additionally, Figure 2 clearly exhibit volatility clustering, that is, large changes tend to be followed by large changes of either sign and small changes tend to be followed by small changes in all cases, which allow us to proceed further to apply the ARCH type processes.

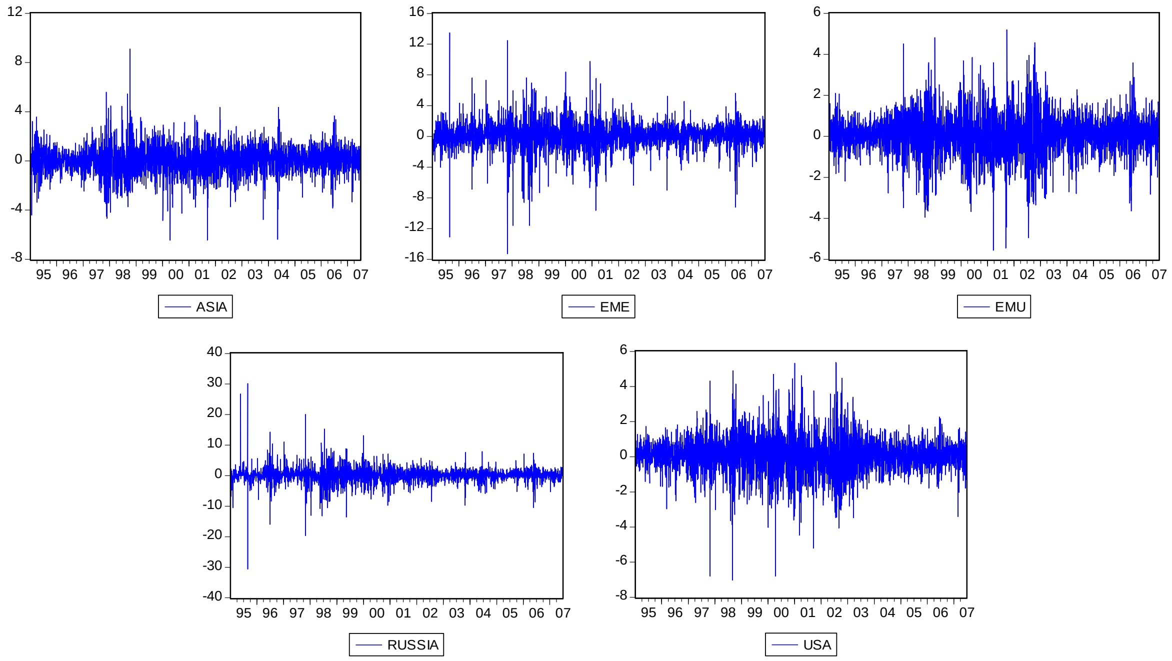

Figure 2: The daily return series of Asian, Emerging Europe, European Union, US and Russian equity market indices in USD terms from 1995 to 2007.

4 EMPIRICAL RESULTS

4.1 International linkage of Russian Market

Our empirical results answer the theoretical questions formulated in the previous sections. First, to examine the international linkage of Russian stock market four pair-wise models are estimated utilizing bivariate GARCH frame work, for which a BEKK representation is adopted. The modelled pairs are Russia - USA, Russia - European Union, Russia - Emerging Europe and Russia – Asia, using daily total return indices calculated by DataStream from January 1995 to June 2007.

We first look at matrix β in the mean equation, Eq. (1), captured by the parameters c_{ij} in Table 2, in order to see the relationship in terms of returns across the countries in each pair. As the diagonal parameters c_{11} and c_{22} for all the modelled pairs except with Emerging Europe (c_{22}) are statistically significant, suggesting that the returns of Russia, USA, European Union, and Asia all depend on their first lags. In contrast, the insignificant diagonal parameter of Emerging Europe (c_{22}) indicates that the returns of Emerging Europe do not depend on their own past returns.

Next we examine the estimated results of the time-varying variance–covariance Eq. (4) in the system. The matrices A and G reported in Table 2 help examine the relationship in terms of volatility as stated in Eq. (4). The diagonal elements in matrix A capture the own ARCH effect, while the diagonal elements in matrix G measure the own GARCH effect. As shown in Table 2, the estimated diagonal parameters, a_{11}, a_{22} and g_{11}, g_{22} are all statistically significant, indicating a strong GARCH (1, 1) process driving the conditional variances of the four pair wise indices. In other words, own past shocks and volatility effect the conditional variance of Russia, USA, EU, Emerging Europe and Asian indices.

The off-diagonal elements of matrices *A* and *G* capture the cross-market effects such as shock and volatility spillovers among the four pairs. First, we document shock transmissions between Russia and other markets, we found bi-directional correlation of Russia with EU and Emerging Europe, as the pairs of off-diagonal parameters, a_{12} and a_{21}, are both statistically significant. This indicates a strong connection between Russia and Europe, both developed and emerging. Further, we evidence uni-directional link between Russia and Asia, interestingly the direction is from Asia to Russia, as only the off-diagonal parameter a_{21} is statistically significant. Meaning, Asian shocks (e.g., Asian crisis of 1997) have affected the mean returns in Russian equity market. No mean effects were found between Russia and USA during the period studied. Second, we explain the volatility spillovers between Russia and other regions of the world. We found bi-directional volatility linkages between Russia and all other markets as both g_{12} and g_{21} are statistically significant in all cases.

These results show clear evidence of Russian market integration with rest of the world, particularly the sample set used in this study. However, the degree of integration is found very week as the magnitude of estimated coefficients is very low. Moreover, one can argue that Russia is strongly linked with rest of the world in terms of volatility.

4.2 Effects of Russian Crisis 1998

Next we answer our second question, the contagion effects of Russian crisis of 1998 and the volatility transmission from Russia to rest of the world before and after the crisis. For this purpose we split our data in to three subsets, pre crisis, during crisis and post crisis. Again utilizing the BEKK framework we estimate four pairwise models explained in the previous section using the subsets.

4.2.1 Pre-Crisis period (Jan. 1995- July 1998)

First of all we present our pre crisis analysis in the same fashion as in previous section. We start with the mean equation of the system, results reported in Table 3 show that only Russian returns depends on their first lags, while all other markets does not depend on their first lags always. However, very strong connection of cross market effects was found for all cases during the pre crisis period. Next, we document the shocks and volatility spillovers represented by vector a_{ij} and g_{ij}. Volatility shocks both from the developed and emerging regions, i.e., USA, EU and Emerging Europe has significant affect on Russian market and at the same time news from Russian market also influence on these markets, except EU. While, no links were found among the stock markets of Russia and Asia.

Next consider the volatility spillovers, Russian market is found better integrated with USA and Emerging Europe as compared to Asia and EU. The pair wise estimates revels bi-directional links between Russia and USA, as well as Emerging Europe, which explains the heavy dependence of Eastern Europe on Russia before the crisis and bilateral trade agreements with USA in mid 90's. On the other hand, volatility spillovers are found uni-directional among Russia and EU and Asia, meaning, any news from EU or Asia has direct influence on Russian market but news from Russia does not effect in the same way on those markets. This could be due to the prominent trade ties of Russia and some Asian countries, such as India and on the other hand with some European countries, for instance, Finland, Germany, and Netherlands during the period under investigation.

Finally, the estimated diagonal parameters, a_{11}, a_{22} and g_{11}, g_{22} are all statistically significant, indicating a strong GARCH(1,1) process driving the conditional variances of the four pair wise indices.

4.2.2 During the Crisis period (July 1998- Dec. 1998)

As, it is well documented in the prior literature that during the crisis period the correlations among the markets and countries show an increasing trend. To analyse this phenomena we run our model during the crisis period. Results reported in Table 4 are very interesting and backing the prior research. The dynamics of shock transformation from Russia are found in all regions except EU, while volatility spillovers from Russian market spread all over the world significantly. The transformation has been found unidirectional from Russia to US, Emerging Europe and EU, while with Asia it is bi-directional.
All the estimated diagonal parameters, a_{11}, a_{22} and g_{11}, g_{22} again reveal that in all regions own past volatilities are important to drive the direction. In the mean equation only Russian returns depends on their first lags, while all other markets does not depend on their first lags always. Significant cross market interdependence is found among the pairs of Russia and USA and Emerging Europe.

4.2.3 Post- Crisis period (Jan. 1999- June 2007)

Finally, we examine the post crises period to check the repercussions of Russian financial crisis of 1998, with special reference to the transmission of shocks and volatility and the degree of integration Russian market has achieved, considering the massive correction plans by the Russian government after the crisis.

Our estimated model for post crisis period enable us to report the linkage of Russian market as increased with USA and Asia, where we found two way volatility spillovers. Russian policies still effect on the emerging Europe, although the link between Russia and emerging Europe has weaken after the crisis, as these markets are more linked with Europe then Russia. Interestingly the relationship with EU after the crisis has not been as significant as it was before the crisis.

The mean return effects caused by Russian market are more prominent in Asia and emerging Europe, while US market shocks transmission to Russian market is evident. All the regions show clear patterns of dependence on their own shocks and volatility effects. Mean equation shows that the returns of all markets, except US, depend on their own returns as well and a significant cross market linkage in terms of returns is also found in all markets, except USA.

4.3 Some Diagnostic tests

Panel B of Table 2, 3, 4 and 5 presents Ljung-Box Q statistic which is used to test the null hypothesis that the model is correctly specified, or equivalently, that the noise terms are random. We report both standardized and standardized squared residuals up till lag 24 for each modelled pair. Results show that there is no series dependence in the squared standardized residuals, indicating the appropriateness of the GARCH-BEKK model.

5 SUMMARY AND CONCLUSIONS

In this paper we have examined the international linkage of Russian equity market and the international transmission of the 1998 Russian financial crisis. We use a bivariate GARCH-BEKK model proposed by Engle and Kroner (1995). By utilizing daily total return indices. Four pair-wise models are estimated, namely, Russia–USA, Russia–European Union, Russia –Emerging Europe and Russia–Asia. We find evidence of direct linkage between Russian equity market, both in regards of returns and volatility, with all other markets. However the linkage is week, indicating partial integration of Russian market into world market. While analyzing the contagion effect of Russian Financial crisis 1998, three subsets were examined, pre crisis (1994-1998), during crisis (Aug.1998 – Dec.1998) and post crisis (1999-2007).Volatility spillovers are found in all cases. Though the dynamics of the conditional volatilities differ. USA and Emerging Europe exhibit bidirectional while European Union and Asia display unidirectional linkage in pre crisis sample. Whereas, after the crisis period shows bidirectional connection with USA and Asia while unidirectional ties with Emerging Europe. Surprisingly, no statistically significant relations were found between Russian equity market and the equity markets of European Union in post crisis sample. Finally, highly significant but negative shocks and volatility spillovers were observed from Russia to all other markets during the crisis period, indicating clear evidences of crisis contagion.

Thus, within the context of the Russian financial crisis, our results offers a better understanding of the nature of international interdependence during the crisis period which is very valuable for the international investors, multinational corporations and portfolio managers, who all are involved in minimizing and managing their financial risk exposure. Likewise, international transmission of stock market volatility can impact on corporate capital budgeting decisions, investors' consumption decisions, and other business cycle variables. Finally, week integration of Russian market offer good opportunities to the international investors to diversify their portfolios.

This study can be extended in many directions, a natural extension of the bivariate analysis conducted in the present paper would be to estimate a k-variate model and to examine volatility spillovers among all markets; also, some more recent techniques, such as, constant correlation (CC), time varying correlation (VC) or dynamic constant correlation (DCC). This is left for future work

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Table 1: Summary Descriptive Statistics

		Full sample	sub-samples		
Country	Statistics	1995-2007	1994-1998	1998-1998	1999-2007
Russia	Mean	24.902	21.422	-165.187	37.687
	Std. dev.	39.232	49.700	66.424	31.286
	Skewness	0.098	0.392	0.435	-0.344
	Kurtosis	25.070	30.574	3.668	7.189
	JB	65904.260*	28725.770*	6.613	1658.761*
	ADF	-53.664*	-15.937*	-9.045	-43.669*
	$LB_{(24)}$	58.595*	36.054*	26.946	51.742*
	$LB^2_{(24)}$	532.290*	152.040*	15.270	446.600*
	ARCH-LM	122.613*	39.291*	0.737	35.376*
USA	Mean	10.808	26.582	17.851	3.917
	Std. dev.	16.316	12.330	24.038	17.150
	Skewness	-0.143	-0.762	-0.609	0.065
	Kurtosis	6.983	10.599	6.311	5.852
	JB	2157.150*	2267.411*	68.449	750.117*
	ADF	-56.607*	-9.604*	-11.437	-13.045*
	$LB_{(24)}$	43.930*	44.294*	38.496	42.389*
	$LB^2_{(24)}$	1418.900*	87.130*	27.188	1197.700*
	ARCH-LM	63.737*	12.432*	1.068	52.883*
European	Mean	12.622	22.782	5.424	8.885
	Std. dev.	15.984	11.693	23.900	16.894
	Skewness	-0.260	-0.224	-0.364	-0.202
	Kurtosis	5.439	5.560	3.151	5.125
	JB	841.304*	254.943*	3.049	430.520*
	ADF	-52.959*	-15.768*	-8.827	-15.387*
	$LB_{(24)}$	66.143*	37.413*	40.987	49.140*
	$LB^2_{(24)}$	2258.300*	444.580*	47.915	1293.900*
	ARCH-LM	91.623*	18.648*	1.620	60.727*
Emerging Europe	Mean	19.939	23.722	-91.972	25.075
	Std. dev.	27.980	30.820	48.673	24.856
	Skewness	-0.564	-0.708	-0.345	-0.335
	Kurtosis	11.186	15.443	4.334	7.450
	JB	9238.545*	5920.058*	12.402	1863.983*
	ADF	-36.790*	-6.605*	-3.039	-30.767*
	$LB_{(24)}$	97.330*	52.694*	46.980	51.724*
	$LB^2_{(24)}$	909.110*	268.650*	21.303	606.710*
	ARCH-LM	28.114*	64.134*	1.355	51.928*
Asia	Mean	3.632	-11.497	20.223	8.846
	Std. dev.	17.575	17.044	26.544	17.107
	Skewness	-0.036	0.088	1.337	-0.405
	Kurtosis	6.585	6.246	8.176	5.426
	JB	1739.890*	398.913*	186.703	602.299*
	ADF	-52.863*	-8.327*	-10.866	-43.763*
	$LB_{(24)}$	45.353*	35.518*	30.917	29.428*
	$LB^2_{(24)}$	521.200*	265.140*	18.692	216.970*
	ARCH-LM	131.404*	22.201*	1.620	16.321*

Table 2: Mean and Volatility Spillovers Estimated from a bivariate GARCH (1, 1) -BEKK Model on Daily Return Indices for the Period Jan. 1995– Dec. 2007

The diagonal elements in matrix C represent the mean equation, matrix *A* capture the own and cross market ARCH effect, while the diagonal elements in matrix *G* measure the own and cross market GARCH effect. LB and LB^2 presents Ljung-Box Q statistic for standardized and standardized squared residuals. (*) denotes the significance level at 5%.

	Russia - USA		**Russia - EU**		**Russia - Asia**		**Russia – Emerging Europe**	
Parameters	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
α	0.127*	(0.038)	0.120*	(0.034)	0.113*	(0.036)	0.152*	(0.031)
β	0.067*	(0.016)	0.084*	(0.016)	0.039*	(0.019)	0.149*	(0.025)
C_{11}	1.079*	(0.051)	0.925*	(0.056)	0.955*	(0.050)	0.570*	(0.047)
C_{12}	0.008	(0.014)	0.010	(0.016)	-0.006	(0.027)	0.426*	(0.037)
C_{22}	0.062*	(0.015)	0.077*	(0.015)	0.109*	(0.016)	-0.023	(0.028)
A_{11}	0.614*	(0.028)	0.558*	(0.028)	0.566*	(0.024)	0.609*	(0.028)
A_{12}	-0.009	(0.006)	0.017*	(0.006)	-0.001	(0.007)	0.193*	(0.018)
A_{21}	-0.065	(0.051)	-0.265*	(0.060)	-0.118*	(0.048)	-0.285*	(0.028)
A_{22}	0.191*	(0.014)	0.228*	(0.014)	0.224*	(0.014)	0.104*	(0.020)
G_{11}	0.702*	(0.023)	0.759*	(0.024)	0.755*	(0.019)	0.865*	(0.011)
G_{12}	0.009*	(0.004)	-0.010*	(0.003)	0.008*	(0.004)	-0.059*	(0.006)
G_{21}	0.044*	(0.022)	0.136*	(0.027)	0.057*	(0.030)	0.015	(0.014)
G_{22}	0.977*	(0.003)	0.974*	(0.004)	0.967*	(0.004)	0.968*	(0.009)
LogLik	-11490.838		-11284.787		-11854.200		-11246.751	
LB_i^{+}	110.825*		113.009*		109.092*		104.747*	
LB_j	27.468		34.733		35.166		111.329*	
LB^2_i	2.602		4.029		3.069		10.014	
LB^2_j	34.099		35.819		19.714		54.162*	

+ In every pair (*i*) represents Russian market and (*j*) represent the other market in the pair

Table 3: Mean and Volatility Spillovers Estimated from a bivariate GARCH (1, 1) -BEKK Model on Daily Return Indices for the Period Jan. 1995– July 1998

The diagonal elements in matrix C represent the mean equation, matrix *A* capture the own and cross market ARCH effect, while the diagonal elements in matrix *G* measure the own and cross market GARCH effect. LB and LB^2 presents Ljung-Box Q statistic for standardized and standardized squared residuals. (*) denotes the significance level at 5%.

	Russia - USA		**Russia - EU**		**Russia - Asia**		**Russia – Emerging Europe**	
Parameters	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
α	-0.056	(0.082)	0.007	(0.075)	-0.044	(0.088)	-0.019	(0.076)
β	0.143*	(0.025)	0.123*	(0.024)	-0.006	(0.029)	0.099	(0.054)
C_{11}	-1.401*	(0.106)	-0.381	(0.204)	1.739*	(0.108)	1.287*	(0.096)
C_{12}	0.108*	(0.020)	0.604	(0.036)	-0.074	(0.044)	0.895*	(0.075)
C_{22}	0.000	(0.030)	0.000	(0.520)	0.049	(0.059)	0.000	(0.087)
A_{11}	0.677*	(0.040)	0.827*	(0.046)	0.791*	(0.055)	0.891*	(0.066)
A_{12}	-0.015*	(0.005)	0.021*	(0.009)	0.003	(0.010)	0.320*	(0.036)
A_{21}	-1.488*	(0.107)	-0.010	(0.175)	-0.083	(0.142)	-0.271*	(0.087)
A_{22}	0.237*	(0.026)	0.489*	(0.040)	0.227*	(0.026)	0.165*	(0.051)
G_{11}	0.530*	(0.045)	0.396*	(0.052)	0.442*	(0.064)	0.747*	(0.035)
G_{12}	-0.033*	(0.011)	-0.013	(0.014)	0.008	(0.008)	-0.107*	(0.019)
G_{21}	-1.048*	(0.171)	-2.446*	(0.124)	0.193*	(0.096)	-0.247*	(0.073)
G_{22}	-0.952*	(0.011)	-0.357*	(0.096)	0.969*	(0.007)	0.802*	(0.048)
LogLik	-3169.021		-3063.787		-3384.757		-3473.965	
LB_i^+	34.931		22.704		20.069		79.375*	
LB_j	88.917*		87.942*		93.172*		99.017*	
LB^2_i	10.730		19.015		19.878		21.057	
LB^2_j	1.029		2.041		1.363		2.868	

$^+$In every pair (i) represents Russian market and (j) represent the other market in the pair

Table 4: Mean and Volatility Spillovers Estimated from a bivariate GARCH (1, 1) -BEKK Model on Daily Return Indices for the Period Aug. 1998– Dec. 1998

The diagonal elements in matrix C represent the mean equation, matrix *A* capture the own and cross market ARCH effect, while the diagonal elements in matrix *G* measure the own and cross market GARCH effect. LB and LB^2 presents Ljung-Box Q statistic for standardized and standardized squared residuals. (*) denotes the significance level at 5%.

	Russia - USA		**Russia - EU**		**Russia - Asia**		**Russia – Emerging Europe**	
Parameters	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
α	-0.622	(0.378)	-0.654	(0.373)	-1.083*	(0.331)	-0.660*	(0.313)
β	0.188	(0.117)	0.102	(0.130)	-0.020	(0.137)	-0.285	(0.204)
C_{11}	3.319*	(0.367)	3.074*	(0.475)	1.844*	(0.680)	2.603*	(0.407)
C_{12}	0.446*	(0.165)	0.196	(0.233)	-0.280	(0.308)	1.168*	(0.332)
C_{22}	0.000	(0.692)	0.000	(0.566)	0.000	(0.699)	0.000	(0.303)
A_{11}	-0.656	(0.131)	-0.594*	(0.193)	-0.456*	(0.166)	1.081*	(0.173)
A_{12}	-0.092*	(0.045)	-0.042	(0.056)	0.174*	(0.076)	0.550*	(0.132)
A_{21}	-0.065	(0.323)	-0.006	(0.497)	0.667*	(0.263)	-0.998*	(0.234)
A_{22}	0.290*	(0.111)	-0.333*	(0.120)	0.054	(0.096)	-0.209	(0.174)
G_{11}	0.022	(0.293)	0.236	(0.233)	-0.302	(0.297)	0.324*	(0.117)
G_{12}	-0.215*	(0.075)	-0.111*	(0.050)	-0.339*	(0.044)	-0.384*	(0.069)
G_{21}	-0.510	(0.636)	0.607	(0.434)	-1.699*	(0.465)	0.177	(0.196)
G_{22}	0.780*	(0.162)	1.017*	(0.047)	-0.064	(0.271)	0.946*	(0.097)
LogLik	-600.562		-592.133		-624.094		-648.628	
LB_i^+	23.954		32.238		39.436*		39.436*	
LB_j	21.831		21.586		23.457		23.457	
LB^2_i	25.976		26.743		14.885		14.885	
LB^2_j	17.821		18.773		24.748		24.748	

+In every pair (i) represents Russian market and (j) represent the other market in the pair

Table 5: Mean and Volatility Spillovers Estimated from a bivariate GARCH (1, 1) -BEKK Model on Daily Return Indices for the Period Jan. 1999– Dec. 2007

The diagonal elements in matrix C represent the mean equation, matrix *A* capture the own and cross market ARCH effect, while the diagonal elements in matrix *G* measure the own and cross market GARCH effect. LB and LB^2 presents Ljung-Box Q statistic for standardized and standardized squared residuals. (*) denotes the significance level at 5%.

	Russia - USA		**Russia - EU**		**Russia - Asia**		**Russia – Emerging Europe**	
Parameters	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
α	0.179*	(0.035)	0.196*	(0.042)	0.193*	(0.039)	0.197*	(0.041)
β	0.040*	(0.019)	0.086*	(0.023)	0.064*	(0.024)	0.182*	(0.034)
C_{11}	0.401*	(0.036)	0.317*	(0.039)	0.358*	(0.042)	0.345*	(0.034)
C_{12}	0.063	(0.056)	0.050*	(0.023)	0.084*	(0.037)	0.276*	(0.027)
C_{22}	0.000	(0.073)	0.111*	(0.018)	0.150*	(0.034)	0.045*	(0.009)
A_{11}	0.246*	(0.019)	0.294*	(0.025)	0.305*	(0.025)	0.346*	(0.046)
A_{12}	0.087*	(0.011)	0.014	(0.010)	-0.024	(0.014)	0.064*	(0.032)
A_{21}	-0.280*	(0.041)	0.008	(0.035)	0.019	(0.047)	-0.060	(0.058)
A_{22}	0.215*	(0.020)	0.235*	(0.018)	0.216*	(0.020)	0.212*	(0.043)
G_{11}	0.822*	(0.013)	0.944*	(0.010)	0.941*	(0.010)	0.933*	(0.013)
G_{12}	-0.189*	(0.009)	-0.004	(0.004)	0.016*	(0.007)	-0.026*	(0.009)
G_{21}	0.647*	(0.030)	-0.007	(0.011)	-0.046*	(0.022)	0.004	(0.015)
G_{22}	0.950*	(0.011)	0.965*	(0.006)	0.959*	(0.007)	0.969*	(0.011)
LogLik	-7512.845		-7458.926		-7744.278		-6989.440	
LB_i^+	23.502	0.490	34.108	0.083	29.824	0.191	60.533*	0.000
LB_j	49.627*	0.002	50.085*	0.001	50.350*	0.001	49.668*	0.002
LB^2_i	25.164	0.397	26.241	0.341	182.388*	0.000	30.628	0.165
LB^2_j	14.152	0.943	15.151	0.916	16.132	0.883	15.617	0.901

[+]In every pair (*i*) represents Russian market and (*j*) represent the other market in the pair