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Volatility spillovers and contagion from mature to emerging stock markets

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Abstract

This paper examines volatility spillovers from mature to emerging stock markets and tests for changes in the transmission mechanism—contagion—during turbulences in mature markets. Tri-variate GARCH-BEKK models of returns in global (mature), regional, and local markets are estimated for 41 emerging market economies (EMEs), with a dummy capturing parameter shifts during turbulent episodes. LR tests suggest that mature markets influence conditional variances in many emerging markets. Moreover, spillover parameters change during turbulent episodes. Conditional variances in most EMEs rise during these episodes, but there is only limited evidence of shifts in conditional correlations between mature and emerging markets.

JEL classifications: F30; G15
Keywords: Volatility spillovers; contagion; stock markets; emerging markets

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1. Introduction

The literature on financial contagion is vast. The October 1987 stock market crash in the US and the 1992 ERM crisis gave rise to numerous empirical analyses of the transmission of shocks across *mature* financial markets. Research on financial contagion in *emerging* markets was boosted by the emerging market crises of the 1990s, in particular the Asian crisis. Given the rapid propagation and large economic impact of these crises, contagion

[1] The views expressed in this paper are those of the authors and do not necessarily reflect those of the European Central Bank or the International Monetary Fund. Marianne Schulze-Ghattas was visiting fellow at the Financial Markets Group, London School of Economics when the research was done.

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became virtually synonymous with turbulence in emerging markets and studies of the role of different contagion channels during these crises multiplied.[1] While views on the precise definition of contagion differ, there is a fairly broad consensus in the empirical literature on financial contagion that contagion refers to an unanticipated transmission of shocks. Contagion should thus be distinguished from "normal" interdependencies and spillovers across asset markets.[2]

An important strand of the empirical research on contagion uses conditional correlation analysis to test for shifts in linkages across financial markets during crisis periods.[3] Following the seminal paper by King and Wadhwani (1990), subsequent studies refined this approach by addressing key features of the data generating process that affect the validity of these tests such as heteroscedasticity, endogeneity, and the influence of common factors. (King, Sentana, and Wadhwani (1994), Forbes and Rigobon (2002), Corsetti, Pericoli, and Sbracia (2005), and Caporale, Cipollini, and Spagnolo (2005)). In a related vein, Dungey, Fry, Gonzalez-Hermosillo, and Martin (2002 and 2003) estimated dynamic latent factor models to test for contagion in bond and stock markets during crisis episodes. Based on a factor model that allows for time-varying integration with global markets, Bekaert, Harvey, and Ng (2005) identified contagion as "excess correlation," that is, cross-country correlations of the model residuals during crisis episodes.

Prompted by the widespread repercussions of past financial crises in emerging markets, empirical analyses of contagion involving emerging financial markets have understandably focused on the transmission of shocks originating in these markets, rather than shocks emanating from mature markets.[4] Studies of linkages between mature and emerging financial markets have focused primarily on the implications of market liberalization and integration for return correlations and volatility spillovers, and have generally ignored the possibility of

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[1] Karolyi (2003) and Pericoli and Sbracia (2003) provide comprehensive surveys. Masson (1998), Claessens, Dornbusch, and Park (2001), Kaminsky and Reinhart (2000), and Kaminsky, Reinhart, and Vegh (2003) discuss real and financial transmission channels and review different approaches to the analysis of contagion. Pericoli and Sbracia (2003) and Pritsker (2001) examine channels of financial contagion.

[2] This definition of contagion is consistent with the taxonomy of shocks proposed by Masson (1999). Pericoli and Sbracia (2003) discuss different definitions of contagion.

[3] See Dungey, Fry, Gonzalez-Hermosillo, and Martin (2004) and Pericoli and Sbracia (2003) for a more comprehensive review of different methodologies applied in the contagion literature, including probability models, which examine the impact of a change in a given crisis index for one country on the crisis probability of another country, and models based on extreme value theory, which focus on correlations of extreme negative values of asset return distributions.

[4] One exception is Serwa and Bohl (2005), who include the US stock market crashes following 9/11 and the 2002 accounting scandals in their sample of crisis events and test for contagion in three emerging and seven mature stock markets in Europe after these events. Using variants of the adjusted correlation coefficients proposed by Forbes and Rigobon (2002) and Corsetti, Pericoli, and Sbracia (2005), they find little evidence of contagion.

"shift contagion" during episodes of heightened volatility in mature markets.[5] Several episodes of turbulence in mature financial markets in the past decade, in particular the events of 2007-08, suggest that this may be an important gap in the empirical contagion literature.

This paper offers a first pass at filling this gap. Our analysis builds on the research discussed above but differs from existing studies in three respects. First, we apply the concept of shift contagion to the analysis of spillovers from mature to emerging stock markets and test for shifts in the transmission mechanism during episodes of turbulence in mature markets. We use the Chicago Board Options Exchange index of implied volatility (VIX)—a widely quoted indicator of market sentiment—to identify turbulent episodes in mature markets. Second, we focus on the transmission of volatility, that is, dependencies and possible contagion in the second moments. Third, we cover a large sample of 41 emerging market economies (EMEs) in Asia, Europe, Latin America, and the Middle East, which provides a rich basis for comparisons across countries and regions; most studies to date focus on relatively small sets of countries in one or two regions.

We use a tri-variate VAR-GARCH framework with the BEKK representation proposed by Engle and Kroner (1995) to model the means and variances of stock returns in local, regional, and global (mature) markets, with the latter defined as a weighted average of the US, Japan, and Europe (Germany, France, Italy, and the UK). GARCH models have been applied extensively in analyses of cross-border volatility spillovers in asset markets, though primarily in mature markets.[6]

While we are mainly interested in spillovers from mature markets to local emerging markets, we include a regional market—defined as a weighted average of other emerging markets in the region—in each country model to control for the transmission of shocks originating in these countries.[7] We modify the GARCH model by including a dummy variable that allows for shifts in the parameters capturing spillovers from mature to emerging markets during episodes of turbulence in the former. This approach accommodates multiple shifts between turbulent and tranquil periods.

Our analysis is based on weekly stock returns in local currency. Country samples begin in 1993 for the emerging markets in Asia, and in 1996 for Latin America and most countries in emerging Europe and the Middle East. All samples end in mid March 2008.

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[5] These studies typically estimate factor models with variable factor loadings for returns in foreign markets to capture time-varying market integration. See Bekaert and Harvey (1995, 1997, and 2000) and Ng (2000). However, Bekaert, Harvey, and Ng (2005) extend this analysis to test for contagion during crisis episodes in emerging markets.

[6] Studies of mature markets include Fratzscher (2002), Longin and Solnik (1995), Bae and Karolyi (1994), and Hamao, Masulis and Ng (1990). Caporale, Pittis, and Spagnolo (2006), Ng (2000) and Edwards (1998) examine volatility spillovers in emerging markets.

[7] Bekaert, Harvey, and Ng (2005) adopt a similar approach.

Likelihood Ratio (LR) tests are carried out to examine various hypotheses concerning volatility spillovers from mature stock markets to regional and local emerging markets, and from regional to local markets. Specifically, we consider the following possibilities: no volatility spillovers whatsoever from mature markets; no shift contagion, that is, no change in the transmission of volatility during turbulent periods in mature markets; no volatility spillovers during tranquil periods—a special case of volatility contagion if spillovers are present during turbulent episodes; and no volatility spillovers from regional to local markets. We also examine the model estimates of conditional variances in local emerging stock markets as well as conditional correlations between mature and local emerging markets, and test for changes during turbulent episodes in mature markets.

For the majority of the EMEs analyzed, the LR test results point to volatility spillovers from mature stock markets to local EME markets and to shifts in the spillover parameters during turbulent episodes in mature markets. There is also evidence of volatility spillovers from regional to local EME markets. Conditional variances in most, though not all, local stock markets tend to be higher during turbulent episodes in mature markets than during other periods, but the increase is not always statistically significant. We find relatively few cases of statistically significant increases in conditional correlations between mature and emerging stock markets during episodes of turbulence in the former; nearly all of these are in emerging Europe.

The paper is organised as follows. Section 2 lays out the model. Section 3 provides details on the data set, and on the method used to identify turbulent episodes in mature stock markets. Section 4 outlines the hypotheses tested and discusses the results. Section 5 summarizes the main conclusions.

2. Methodology

2.1. Basic model

We represent the first and second moments of returns in local and regional emerging markets and in mature markets by a tri-variate VAR-GARCH(1,1) process. In its most general specification the model takes the following form:

$$x_t = \alpha + \beta x_{t-1} + u_t \qquad (1)$$

where x_t = (local emerging market returns$_t$, regional emerging market returns$_t$, mature market returns$_t$), x_{t-1} is a corresponding vector of lagged returns, and $u_t = (e_{1,t}, e_{2,t}, e_{3,t})$ is a residual vector. The parameters of the mean return equations (1) comprise the constant terms $\alpha = (\alpha_1, \alpha_2, \alpha_3)$ and the parameters of the autoregressive terms $\beta = (\beta_{11}, \beta_{12}, \beta_{13} \mid 0, \beta_{22}, \beta_{23} \mid 0, 0, \beta_{33})$, which allow for mean return spillovers from mature markets to regional and local emerging markets, and from regional markets to local markets.

The residual vector u_t is tri-variate and normally distributed $u_t \mid I_{t-1} \sim (0, H_t)$ with its corresponding conditional variance covariance matrix:

$$H_t = \begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix} \qquad (2)$$

In the multivariate GARCH(1,1)-BEKK representation proposed by Engle and Kroner (1995), which guarantees by construction that the variance covariance matrices in the system are positive definite, H_t takes the following form:

$$H_t = C'_0C_0 + \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix}' \begin{bmatrix} e_{1,t-1}^2 & e_{1,t-1}e_{2,t-1} & e_{1,t-1}e_{3,t-1} \\ e_{2,t-1}e_{1,t-1} & e_{2,t-1}^2 & e_{2,t-1}e_{3,t-1} \\ e_{3,t-1}e_{1,t-1} & e_{3,t-1}e_{2,t-1} & e_{3,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

$$\begin{bmatrix} g_{11} & 0 & 0 \\ g_{21} & g_{22} & 0 \\ g_{31} & g_{32} & g_{33} \end{bmatrix}' \quad H_{t-1} \begin{bmatrix} g_{11} & 0 & 0 \\ g_{21} & g_{22} & 0 \\ g_{31} & g_{32} & g_{33} \end{bmatrix} \qquad (3)$$

Equation (3) models the dynamic process of H_t as a function of its own past values H_{t-1} and of past values of innovations ($e_{1,t-1}$, $e_{2,t-1}$, $e_{3,t-1}$), allowing for own-market and cross-market influences in the conditional variances. The parameters of (3) are given by C_0, which is restricted to be upper triangular, and two matrices A_{11} and G_{11}. Each of these two matrices has three zero restrictions as we are focusing on volatility spillovers (causality-in-variance) running from mature stock markets to regional and local emerging stock markets, and from regional to local emerging markets.

Given a sample of T observations, a vector of unknown parametersθ, and a 3 x 1 vector of variables x_t, the conditional density function for the model (1)-(3) is:[8]

$$f(x_t \mid I_{t-1}; \theta) = (2\pi)^{-1} \mid H_t \mid^{-1/2} \exp(- [u`_t (H_t^{-1}) u_t] / 2) \qquad (4)$$

The log likelihood function is:

$$\text{Log-Lik} = \Sigma_{t=1}^{T} \log f\,(x_t \mid I_{t-1}; \theta) . \qquad (5)$$

[8] Standard errors (SEs) are calculated using the quasi-maximum likelihood method of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals. A residual vector u_t following the t-student distribution has also been considered. Results are qualitatively similar and therefore not reported. The complete set of results is available from the authors upon request.

2.2. Volatility contagion

Applying the concept of shift contagion (Forbes and Rigobon (2002)) to the analysis of interdependencies in second moments, we define volatility contagion as a shift in the transmission of volatility from mature to emerging stock markets during episodes of turbulence in the former. In order to test for such shifts, we include a dummy D in equation (3) that allows the parameters governing volatility spillovers from mature markets to change in these episodes. The equation for the conditional variance of returns in local emerging markets illustrates the modified variance-covariance equations:

$$
\begin{aligned}
h_{11,t} = {} & c_{11}^2 + a_{11}^2\, e_{1,t-1}^2 + a_{21}^2\, e_{2,t-1}^2 + (a_{31} + a_{31d} \cdot D)^2\, e_{3,t-1}^2 \\
& + 2\, a_{11}a_{21}e_{1,t-1}e_{2,t-1} + 2\, a_{11}(a_{31} + a_{31d} \cdot D)\, e_{1,t-1}e_{3,t-1} + 2\, a_{21}(a_{31} + a_{31d} \cdot D)\, e_{2,t-1}e_{3,t-1} \\
& + g_{11}^2\, h_{11,t-1} + g_{21}^2\, h_{22,t-1} + (g_{31} + g_{31d} \cdot D)^2\, h_{33,t-1} \\
& + 2\, g_{11}g_{21}h_{12,t-1} + 2\, g_{11}(g_{31} + g_{31d} \cdot D)\, h_{13,t-1} + 2\, g_{21}(g_{31} + g_{31d} \cdot D)\, h_{23,t-1} \qquad (6)
\end{aligned}
$$

Volatility spillovers from mature stock markets to local and regional emerging markets are reflected in the parameters a_{31} and g_{31}, and a_{32} and g_{32}, respectively; a_{31d} and g_{31d}, and a_{32d} and g_{32d} capture shifts in these parameters during episodes of turbulence in mature markets. Volatility spillovers from regional to local emerging markets are reflected in the parameters a_{21} and g_{21}, which do not change as we are focusing on episodes of turbulence in mature equity markets.

3. Data and identification of turbulent episodes in mature markets

3.1. Data set

The tri-variate GARCH model outlined in the preceding section was estimated for 41 EMEs across four geographical regions: Asia, emerging Europe and South Africa, Latin America, and the Middle East and North Africa.

The model for each EME consists of local stock returns, a weighted average of returns in other EMEs in the region, and a weighted average of mature market returns. Weekly returns were calculated as log differences of local currency stock market indices for weeks running from Wednesday to Wednesday to minimize effects of cross-country differences in weekend market closures. The time series for the Asian EMEs start in September 1993 and the majority of the series for Latin America, emerging Europe, and the Middle East begin in 1996. All return series end in mid-March 2008. Table 1 shows start and end dates of the return series for each EME in the country sample and for the six mature markets included in the aggregate mature market index as well as key descriptive statistics, which point to skewness in most, and kurtosis in many of the return series. All stock market indices were obtained from Datastream.

Insert Table 1 here

For each EME, a regional market was defined as a weighted average of all other sample EMEs in the region. Mature market returns were calculated as a weighted average of returns on benchmark indices in the US, Japan, and Europe (France, Germany, Italy, UK). As complete time series on market capitalization are not available for all EMEs in our sample, weights are based on 104-week moving averages of US$-GDP data from the IMF's World Economic Outlook database.

3.2. Identification of turbulent episodes in mature stock markets

The definition of the crisis window can significantly affect the results of contagion tests. There is relatively broad consensus on the major emerging market crises that have been examined in the empirical contagion literature, even though dating the start and end of these crises is not straightforward.[9] By contrast, what may be considered a "crisis" in mature financial markets is less obvious, perhaps with the exception of the 1987 US stock market crash and the 1992 ERM crisis, which have been extensively studied and precede the start of our EME data samples, and the crisis that began in 2007, which has not yet ended.

In the absence of an agreed definition of turbulence in mature financial markets, we use the Chicago Board Options Exchange index of implied volatility from options on the US S&P 500 (VIX), a widely quoted indicator of market sentiment, to identify episodes of turbulence in mature stock markets. Specifically, we define market turbulence as a period in which the VIX is either very high (30 or higher) or rising sharply (five-day moving average exceeding the 52-week moving average by 30 percent or more).[10] Based on this definition, turbulent episodes are fairly rare events. Thirteen percent of the observations in the full data sample running from June 1993 to March 2008 fall into this category, with clusters in 1996-98, 2001, 2002, early 2003, 2007, and 2008, which are in line with anecdotal evidence. Table 2 lists the weeks in which the turbulence dummy takes the value one.

Insert Table 2 here

4. Empirical analysis

4.1. Hypotheses tested

We test for volatility spillovers and contagion by placing restrictions on the relevant parameters and computing a likelihood ratio test statistic (LR) between the unrestricted and

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[9] Caporale, Cipollini, and Spagnolo (2005) select the breakpoints marking the beginning of the crises in each of the Asian crisis countries endogenously. Most other studies of contagion identify crisis windows in a more ad hoc manner.

[10] Daily data on the VIX were obtained from Datastream.

restricted models, where $LR = -2(L_R - L_U) \sim \chi(k)$. The tests involve joint hypotheses at two and four degrees of freedom (k). We test two sets of null hypotheses H0:

(i) Tests of no volatility spillovers or contagion to local emerging markets

H01: No spillovers and no contagion from mature stock markets: $a_{31} = a_{31d} = g_{31} = g_{31d} = 0$. The null hypothesis assumes that volatility in local emerging stock markets is never influenced by volatility in mature markets, neither over the full sample period nor specifically during episodes of turbulence in mature markets.

H02: No contagion, that is, no shift in the transmission of volatility from mature markets to local emerging markets during episodes of turbulence in the former: $a_{31d} = g_{31d} = 0$.

H03: No spillovers from mature markets to local emerging markets over the full sample period: $a_{31} = g_{31} = 0$. This hypothesis complements H02. If we reject H03 and do not reject H02, there is no volatility contagion, only spillovers; if we do not reject H03 and reject H02, volatility is transmitted from mature markets to local emerging markets only during episodes of turbulence in the latter, which implies "shift contagion."

H04: No spillovers from regional to local emerging markets. This implies $a_{21} = g_{21} = 0$ as we are not allowing for shifts in the transmission of volatility from regional to local emerging markets.

We test the same hypotheses, except H04, for regional emerging markets, which may act as a conduit for volatility transmission to local emerging markets.

(ii) Tests of no volatility spillovers or contagion to regional emerging markets

H05: No spillovers and no contagion from mature markets to regional emerging markets: $a_{32.} = a_{32d} = g_{32.} = g_{32d} = 0$.

H06: No shift contagion from mature markets to regional emerging markets during turbulent episodes in the former: $a_{32d} = g_{32d} = 0$.

H07: No spillovers from mature markets to regional emerging markets over the full sample period: $a_{32} = g_{32} = 0$.

Tests of the hypotheses outlined above shed light on volatility linkages between mature and emerging stock markets but they say nothing about the sign of the effects. While the concepts of spillovers and contagion are generally associated with positive linkages, negative linkages cannot be ruled out.[11] However, tracing the impact of "news surprises" in mature stock markets on emerging markets is not straightforward. Given the non-linearity of GARCH models, the impact of a surprise in mature stock market depends on all other variables in the system, that is, surprises in local and regional markets as well as past variances and co-

[11] Favero and Giavazzi (2002).

variances.[12] As such time-dependent impulse response functions are quite difficult to interpret, we simply compare the conditional variances in local emerging stock markets predicted by our model for turbulent and non-turbulent periods in the full sample 1996-2008, and sub-samples 1996-99, 2000-03, and 2004-08.[13] We test the null hypothesis of equal conditional variances against the alternative that conditional variances in emerging markets are higher during turbulent episodes in mature markets. While these tests cannot be interpreted as evidence of positive volatility spillovers from mature markets, they provide useful information about volatility in local emerging stock markets during episodes of turbulence in mature markets.

Finally, we compute conditional correlations between local emerging and mature market returns as $h_{13}/(\sqrt{h_{11}}\sqrt{h_{33}})$ and test for differences between conditional correlations during turbulent and non-turbulent periods in mature markets. These tests are carried out for the full sample 1996-2008, and for sub-samples 1996-99, 2000-03, and 2004-08.

4.4. Discussion of Results

For most of the 41 EMEs in our country set, the estimated tri-variate VAR-GARCH(1,1) model appears to capture the evolution of conditional means and variances of local stock returns, and their interactions with regional and mature markets, quite well. Ljung-Box portmanteau (LB) autocorrelations tests of ten lags reject the null hypothesis of no autocorrelation in the standardized residuals in only six cases, and the null hypothesis of no autocorrelation in the standardized squared residuals in only one case (Table 3).

Insert Table 3 about here

The parameter estimates for the conditional means of emerging market returns suggest statistically significant spillovers-in-mean from mature stock markets to local markets for half of the EMEs analyzed. This includes all but one of the Asian emerging markets and nearly half of the countries in emerging Europe. By contrast, the estimates of the mean spillover parameter are insignificant (and negative) for all Latin American countries, except Brazil, and insignificant (though positive) for most countries in the Middle East and North Africa, except Egypt and Morocco. On the other hand, the estimated parameters of spillovers-in-mean from regional to local emerging markets are insignificant for all of emerging Asia, but positive and significant for half of the countries in Latin America, close to half of emerging Europe, as well as Kuwait and Lebanon in the Middle East.

The differences across regions in the parameters capturing spillovers-in-mean from regional emerging and global mature markets to local markets are striking, particularly for Asia and Latin America.[14] Common factors not explicitly included in our model may explain part of

[12] Thus, impulse response functions depend on the shock and the time at which arrives.

[13] In order to facilitate cross-country comparisons, we drop pre-1996 data, which are available only for Asia.

[14] The results for Asia are broadly in line with those obtained by Ng (2000) who emphasizes the importance of global factors relative to regional factors in Pacific Basin stock markets.

this variation. Common factors relevant to the manufactures-exporting EMEs in Asia and Europe may be captured fairly well by mature market returns and, hence, are reflected in spillovers from mature markets to local emerging markets. In contrast, common factors relevant to the commodity-exporting emerging markets in Latin America may be less closely linked to mature stock markets and manifest themselves in stronger co-movements across the region and spillovers from regional to local markets.[15]

The estimated "own-market" coefficients of the conditional variances are statistically significant for all EMEs but one, and the estimates of g_{11} suggest a high degree of persistence, except in a few countries in Latin America and emerging Europe, and most countries in the Middle East and North Africa (Table 4.1.and 4.2). There is substantial evidence of spillovers-in-variance from mature stock markets to local emerging markets. While many of the estimated spillover coefficients have fairly large standard errors, at least one of the four parameters capturing these spillovers—in many cases one (or both) of the shift parameters—is significant for close to three quarters of the EMEs in our country sample.

Insert Tables 4.1 and 4.2 about here

The LR tests strongly reject the null hypothesis of no volatility spillovers whatsoever from mature markets (H01) for nearly three quarters of the EME sample, including all EMEs in Asia, except China and the Philippines; all countries in Latin America, except Venezuela; and over two thirds of the countries in emerging Europe (Table 5).[16] These tests also suggest that the transmission of volatility changes during turbulent episodes in mature markets. Indeed, stock markets in a number of EMEs appear to be affected only during such periods. While the hypothesis of no shift in the spillover parameters during turbulent episodes in mature markets (H02) is rejected for close to three quarters of the countries, we reject the hypothesis of no volatility spillovers over the whole sample period (H03) for less than half of the EMEs covered. We find evidence of spillovers over the whole sample period but no shifts in the parameters only for four countries (Colombia, Estonia, India, and Indonesia). For the majority of the EMEs analyzed, LR tests also reject the null hypothesis of no spillovers-in-variance from regional to local emerging markets (H04). In most of the estimated country models, these regional markets are in turn affected by spillovers from mature markets (H05, H06, and H07) and may thus act as a conduit for volatility transmission.

Insert Table 5 about here

[15] An alternative explanation for the observed differences in regional spillover effects would be that stock markets in Latin America are more interdependent than stock markets in emerging Asia; that is, idiosyncratic local shocks are more likely to become regionalized in the former than in the latter. However, empirical evidence on linkages across local markets in Asia before and after the Asian crisis does not support this view (see Caporale, Cipollini, and Spagnolo (2005)).

[16] Caporale, Pittis, and Spagnolo (2006), using a bootstrap procedure, found that the LR test has finite-sample Type-I error probabilities that do not differ significantly from the value of 0.05, with empirical rejection frequencies reasonably close to the corresponding asymptotic ones. Given these results and the large size of our country sample, we did not bootstrap the LR tests.

While it is difficult to quantify the impact of volatility spillovers from mature to emerging stock markets, given the non-linearity of GARCH models, we find that conditional variances of local emerging stock markets have tended to be higher during turbulent periods in mature markets than during non-turbulent periods. This difference is statistically significant in nearly half of our country sample (Table 6). Tests for the three sub-samples 1996-99, 2000-03, and 2004-08 reveal marked differences across these periods. During 1996-99, when turbulence in mature markets coincided, and indeed was likely affected, by turbulence in several emerging markets, statistically significant volatility "shifts" occurred in more than half of the EMEs outside the Middle East and North Africa. By contrast, during the mature market turbulences of 2000-03—which include 9/11, the bursting of the dotcom bubble, and the Enron/Worldcom events—conditional variances in nearly two thirds of the EMEs were, in fact, lower than during non-turbulent episodes. During 2004-08—a period featuring large capital inflows to EMEs—mature market turbulences coincide with increased local market volatility in three quarters of the country sample, but fewer than half of these shifts are statistically significant.

Insert Table 6 about here

We find only limited evidence of a rise in conditional correlations between returns in mature markets and local emerging market during turbulent episodes in the former (Table 7). Even though conditional correlations for the whole sample period are higher during these episodes in most EMEs, the increase is statistically significant in only seven countries, five of which are in emerging Europe (Czech Republic, Israel, Latvia, Poland, and Romania). A comparison of the three sub-samples suggests that increases in conditional correlations during turbulences in mature markets have become more common (but are still fairly rare) in the most recent period, were rare during 2000-03, and completely absent during 1996-99.[17]

Insert Table 7 about here

5. Conclusions

The main objective of this study was to examine volatility spillovers, that is, causality in variance, running from mature to emerging stock markets—a relatively under-researched topic in the vast literature on financial market spillovers and contagion. We estimated tri-variate GARCH-BEKK models covering returns in local emerging markets, regional emerging markets, and mature markets for each of the 41 EME in our country sample, and applied LR tests to examine the presence of such spillovers. As we were particularly interested in the question of whether spillover parameters change during episodes of

[17] These results are at variance with the findings of Forbes and Rigobon (2002), who argue that conditional correlations tend to rise during crisis episodes simply on account of the rise in volatility in the crisis country. However, they are consistent with the analysis of Bartram and Wang (2005), who show that when volatility rises in the crisis *and* the non-crisis country, conditional correlations between the two markets do not necessarily increase during crisis episodes.

turbulence in mature markets, we included a dummy variable in the country models to capture possible "shift" contagion in second moments.

The results presented in this paper are a "first cut" and further analyses are no doubt needed to explore the linkages between mature and emerging stock markets during turbulences in the former. Nonetheless, our analysis provides a number of interesting insights. In particular, it suggests that spillovers from mature markets do influence the dynamics of conditional variances of returns in many local and regional emerging stock markets. Moreover, it indicates that the spillover parameters change during turbulent episodes in mature markets. We reject the null hypothesis of no spillovers or contagion for some three quarters of the EMEs analyzed, and we reject the null of no shift in the spillover parameters for most of these countries. Indeed, in a number of EMEs, spillovers from mature markets appear to be present only during turbulent episodes in these markets.

Whether a rise in mature market volatility increases or decreases volatility in local emerging markets depends on the state of the system at the time of the shock, that is, the impulse response varies over time. Given the difficulty of "aggregating" these time-variant impulse response functions, we compared the conditional variances in local emerging stock markets during turbulent and non-turbulent periods in mature markets to gain insight into the behavior of volatility in local emerging stock markets during these episodes. These comparisons suggest that in most EMEs local market volatility tended to be higher during turbulent episodes in mature markets, though the rise is not always statistically significant.

Finally, broadly in line with the evidence on conditional correlations across emerging markets during past emerging market crises, we find only limited evidence of shifts in conditional correlations between mature and emerging stock markets during episodes of turbulence in the former. Statistically significant increases in conditional correlations are largely confined to emerging Europe and the most recent sub-period of our sample.

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Table 1
Data sample and key descriptive statistics 1/

	Start date 2/	End date 2/	Mean	SD	Skewness	Kurtosis
Emerging Asia						
China	1-Sep-93	12-Mar-08	0.00197	0.04521	0.90951	12.09253
Hong Kong SAR	1-Sep-93	12-Mar-08	0.00154	0.03432	-0.49886	1.59793
India	1-Sep-93	12-Mar-08	0.00254	0.03836	-0.48152	1.87077
Indonesia	1-Sep-93	12-Mar-08	0.00245	0.03619	-0.17987	2.02423
Korea	1-Sep-93	12-Mar-08	0.00113	0.04199	-0.16732	1.76262
Malaysia	1-Sep-93	12-Mar-08	0.00056	0.03569	0.41612	8.98972
Pakistan	1-Sep-93	12-Mar-08	0.00321	0.03963	-0.46194	2.24704
Philippines	1-Sep-93	12-Mar-08	0.00067	0.03645	0.06479	1.55645
Singapore	1-Sep-93	12-Mar-08	0.00112	0.02983	0.01252	3.26267
Sri Lanka	1-Sep-93	12-Mar-08	0.00163	0.03249	-0.23040	5.06578
Taiwan	1-Sep-93	12-Mar-08	0.00099	0.03508	-0.10300	1.14058
Thailand	1-Sep-93	12-Mar-08	-0.00019	0.04026	0.15891	1.46869
Latin America						
Argentina	3-Jan-96	12-Mar-08	0.00223	0.04843	-0.38497	3.21804
Brazil	3-Jan-96	12-Mar-08	0.00417	0.04713	-0.52527	8.03884
Chile	3-Jan-96	12-Mar-08	0.00131	0.01966	-0.21493	2.22802
Colombia	3-Jan-96	12-Mar-08	0.00242	0.02854	-0.52019	4.95411
Ecuador	3-Jan-96	12-Mar-08	-0.00089	0.03558	0.49708	19.75958
Mexico	3-Jan-96	12-Mar-08	0.00368	0.03472	-0.10979	1.78981
Peru	3-Jan-96	12-Mar-08	0.00417	0.03181	-0.42330	4.52347
Venezuela	3-Jan-96	12-Mar-08	0.00449	0.04656	0.75198	7.05673
Emerging Europe						
Bulgaria	1-Nov-00	12-Mar-08	0.00667	0.03818	0.12418	5.46190
Croatia	15-Jan-97	12-Mar-08	0.00274	0.03727	-0.41246	5.74537
Czech Republic	12-Jun-96	12-Mar-08	0.00169	0.03053	-0.54101	1.48161
Estonia	12-Jun-96	12-Mar-08	0.00308	0.04394	-0.50995	7.71378
Hungary	12-Jun-96	12-Mar-08	0.00331	0.03743	-0.53996	2.74571
Israel	12-Jun-96	12-Mar-08	0.00253	0.02913	-0.22223	1.32490
Latvia	12-Jun-96	12-Mar-08	0.00199	0.05153	-2.29692	30.33932
Poland	12-Jun-96	12-Mar-08	0.00220	0.03373	-0.31542	1.68584
Romania	1-Oct-97	12-Mar-08	0.00379	0.04630	-0.30521	5.36750
Russia	12-Jun-96	12-Mar-08	0.00758	0.07135	0.04749	4.83145
Slovakia	12-Jun-96	12-Mar-08	0.00123	0.02799	0.22430	3.22648
Slovenia	12-Jun-96	12-Mar-08	0.00312	0.02590	0.29134	8.00201
South Africa	12-Jun-96	12-Mar-08	0.00694	0.06526	-0.25816	2.75724
Turkey	12-Jun-96	12-Mar-08	0.00261	0.02805	-0.81123	3.45984
Middle East and North Africa						
Egypt	31-Jan-96	12-Mar-08	0.00418	0.03625	0.06108	1.79620
Jordan	31-Jan-96	12-Mar-08	0.00272	0.02117	0.33736	2.19251
Kuwait	31-Jan-96	12-Mar-08	0.00303	0.01852	-0.33012	1.56552
Lebanon	31-Jan-96	12-Mar-08	0.00058	0.03052	0.52233	4.50099
Morocco	31-Jan-96	12-Mar-08	0.00274	0.02016	0.02952	3.12903
Saudi Arabia	7-Jan-98	12-Mar-08	0.00287	0.03313	-1.99019	13.48295
Tunisia	7-Jan-98	12-Mar-08	0.00183	0.01320	1.40272	6.87344
Mature markets						
France	1-Sep-93	12-Mar-08	0.00102	0.02942	-0.19563	3.52991
Germany	1-Sep-93	12-Mar-08	0.00163	0.03160	-0.59749	3.79634
Italy	1-Sep-93	12-Mar-08	0.00115	0.02856	-0.41960	1.69395
Japan	1-Sep-93	12-Mar-08	-0.00062	0.02871	-0.04370	1.02551
UK	1-Sep-93	12-Mar-08	0.00083	0.02255	-0.00717	3.60290
US	1-Sep-93	12-Mar-08	0.00138	0.02140	-0.16522	2.05805

1/ All stock market indices are from Datastream. 2/ Week ending.

Table 2
Episodes of turbulence in mature stock markets (week ending)

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	6-Apr		13-Mar	29-Oct	19-Aug	27-Jan		21-Mar	17-Jul	29-Jan			24-May	7-Mar	9-Jan
	13-Apr		20-Mar	5-Nov	26-Aug	10-Feb		4-Apr	24-Jul	5-Feb			14-Jun	25-Jul	23-Jan
			27-Mar	12-Nov	2-Sep			11-Apr	31-Jul	12-Feb			21-Jun	1-Aug	30-Jan
			3-Apr	19-Nov	9-Sep			12-Sep	7-Aug	19-Feb			19-Jul	8-Aug	6-Feb
			10-Apr	26-Nov	16-Sep			19-Sep	14-Aug	26-Feb				15-Aug	13-Feb
			17-Jul	24-Dec	23-Sep			26-Sep	28-Aug	5-Mar				22-Aug	12-Mar
			24-Jul		30-Sep			3-Oct	4-Sep	12-Mar				29-Aug	
			31-Jul		7-Oct			10-Oct	11-Sep	19-Mar				5-Sep	
					14-Oct			17-Oct	18-Sep					12-Sep	
					21-Oct			24-Oct	25-Sep					19-Sep	
					28-Oct			31-Oct	2-Oct					26-Sep	
								7-Nov	9-Oct					24-Oct	
									16-Oct					31-Oct	
									23-Oct					7-Nov	
									30-Oct					14-Nov	
									6-Nov					21-Nov	
									13-Nov					28-Nov	
														5-Dec	
														19-Dec	

Table 3
Parameter estimates for mean equations and LB test statistics

	Local markets					Regional markets			
	β_{11}	β_{12}	β_{13}	$LB_{(10)}$	$LB^2_{(10)}$	β_{22}	β_{23}	$LB_{(10)}$	$LB^2_{(10)}$
Emerging Asia									
China	0.081 ***	0.024	0.096 ***	12.70	7.75	0.052	0.126 *	12.70	7.75
Hong Kong	-0.028	-0.041	0.115 *	10.64	7.89	0.055 ***	0.175 *	10.64	7.89
India	0.020	0.053	0.215 *	17.87 ***	3.84	0.072 ***	0.133 ***	17.87 ***	3.84
Indonesia	0.020	-0.017	0.303 *	21.76 ***	7.85	0.090 *	0.123 *	21.76 ***	7.85
Korea	-0.058	0.019	0.211 *	13.63	10.15	0.032	0.163 *	13.63	10.15
Malaysia	-0.022	0.054	0.122 **	12.77	7.70	0.067 ***	0.154 *	12.77	7.70
Pakistan	0.136 *	0.075	0.157 *	16.73 ***	15.13	0.091 **	0.135 *	16.73 ***	15.13
Philippines	-0.026	0.046	0.257 *	9.20	10.62	0.074 **	0.142 ***	9.20	10.62
Singapore	-0.008	0.008	0.218 *	8.09	12.42	0.060 ***	0.151 *	8.09	12.42
Sri-Lanka	0.232 *	0.039	0.023	4.59	9.44	0.088 **	0.141 *	4.59	9.44
Taiwan	0.012	0.024	0.137 **	7.81	15.58	0.029	0.137 *	7.81	15.58
Thailand	0.045	-0.027	0.199 *	8.58	5.58	0.068 ***	0.139 *	8.58	5.58
Latin America									
Argentina	0.008	0.090	-0.047	10.05	7.65	-0.041	0.116 **	10.05	7.65
Brazil	-0.115 *	0.037	0.201 **	12.92	5.20	0.077 **	-0.050	12.92	5.20
Chile	0.155 *	0.074 *	-0.055	11.08	16.02	-0.071 ***	0.151 *	11.08	16.02
Colombia	0.160 *	0.068 ***	-0.019	8.40	5.15	-0.019	0.078	8.40	5.15
Ecuador	0.133 **	0.061	-0.114	12.42	7.97	-0.014	0.051	12.42	7.97
Mexico	-0.028	0.022	-0.069	4.75	19.75	-0.016	0.074	4.75	19.75
Peru	0.131 *	0.091 **	-0.010	15.82	4.91	-0.050	-0.020	15.82	4.91
Venezuela	0.123	0.108 **	-0.119	13.41	3.76	-0.048	0.105 ***	13.41	3.76
Emerging Europe									
Bulgaria	0.151 *	0.141 **	-0.195 **	5.20	10.63	0.002	0.127 *	5.20	10.63
Croatia	0.010	0.082 **	0.225 *	7.54	7.44	0.004	0.157 *	7.54	7.44
Czech Republic	-0.039	0.054	0.026	20.60 **	4.81	0.031	0.101 **	20.60 **	4.81
Estonia	0.092 **	0.136 *	0.080	6.91	14.56	0.015	0.150 *	6.91	14.56
Hungary	-0.069 **	0.089 **	0.174 *	12.42	11.41	0.013	0.119 **	12.42	11.41
Israel	-0.074 ***	0.035	0.162 *	10.77	5.62	0.085 **	0.134 **	10.77	5.62
Latvia	0.095 **	0.216 *	0.071	9.17	4.06	0.019	0.157 *	9.17	4.06
Poland	-0.074 ***	0.064	0.135 ***	10.05	7.04	0.030	0.136 **	10.05	7.04
Romania	0.104 **	0.147 *	-0.007	6.31	10.79	0.005	0.103 *	6.31	10.79
Russia	-0.001	0.071	0.116	8.00	6.83	0.019	0.149 *	8.00	6.83
Slovakia	0.096 **	0.014	-0.038	11.17	5.24	0.042	0.105 **	11.17	5.24
Slovenia	0.059	0.031	0.075 ***	13.04	10.56	0.034	0.094 ***	13.04	10.56
South Africa	-0.049	0.004	0.019	9.47	1.62	0.016	0.144 **	9.47	1.62
Turkey	-0.132 *	0.127	0.253 **	15.73	13.61	0.011	0.088 **	15.73	13.61
Middle East and North Africa									
Egypt	0.079 **	0.071	0.164 **	6.33	11.84	0.279 **	0.038	6.33	11.84
Jordan	0.124 **	0.060	0.009	10.37	13.80	0.198 *	0.056	10.37	13.80
Kuwait	0.147 *	0.111 *	0.012	17.60 ***	7.98	0.222 *	0.048	17.60 ***	7.98
Lebanon	-0.103 ***	0.116 **	0.038	15.55	5.03	0.214 *	0.050 **	15.55	5.03
Morocco	0.259 *	0.029	0.071 *	11.95	8.63	0.217 *	0.052	11.95	8.63
Saudi Arabia	0.209 *	-0.013	0.077 **	6.66	17.93 ***	0.156 *	0.092 *	6.66	17.93 ***
Tunisia	0.101 ***	0.006	0.013	16.79 ***	5.64	0.211 *	0.064 ***	16.79 ***	5.64

Notes: *, **, and *** denote significance at the 1%, 5% and 10% levels. Standard errors (not reported) are calculated using the quasi-ML method of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals. LB(10) and LB2(10) indicate the Ljung-Box autocorrelations test for ten lags in the standardized and standardized squared residuals; *, ** and *** denote rejection of the null of no autocorrelation at the 1%, 5% and 10% levels. A residual vector u_t with a t-student distribution has also been considered. The results (not reported) are qualitatively similar. The full set of results is available upon request.

Table 4.1

Parameter estimates for variance-covariance equations: Emerging Asia and Latin America

	Local markets										Regional markets					
	a_{11}	g_{11}	a_{21}	g_{21}	a_{31}	a_{31d}	$a_{31}+a_{31d}$	g_{31}	g_{31d}	$g_{31}+g_{31d}$	a_{32}	a_{32d}	$a_{32}+a_{32d}$	g_{32}	g_{32d}	$g_{32}+g_{32d}$
Emerging Asia																
China	0.275 *	0.953 *	0.002	-0.002	0.006	-0.049	-0.043	0.010	-0.026	-0.016	-0.199 **	0.934 **	0.735	0.268 **	-0.043	0.225
Hong Kong	0.250 *	0.967 *	-0.136 **	0.062 ***	0.014	-0.140 *	-0.126	-0.008	0.086 *	0.078	-0.048 ***	0.134	0.086	0.045	-0.104	-0.059
India	0.319 *	0.922 *	0.019	-0.007	0.047	-0.049	-0.002	-0.016	-0.003	-0.019	-0.025	0.188 **	0.163	0.013	-0.031	-0.018
Indonesia	0.223 *	0.961 *	0.067 *	-0.027 **	0.006	0.069	0.075	-0.009	-0.023	-0.032	-0.019	-0.129 **	-0.148	0.035 *	0.065 *	0.100
Korea	0.268 *	0.957 *	-0.025	0.008	0.072 *	-0.189 *	-0.117	-0.019 **	0.051 **	0.032	-0.035	0.092	0.057	0.023	0.012	0.035
Malaysia	0.328 *	0.948 *	0.054 ***	-0.013	0.022	-0.062	-0.040	-0.007	0.029	0.022	-0.019	-0.053	-0.072	0.028 *	0.039	0.067
Pakistan	0.405 *	0.807 *	0.009	-0.025	-0.015	-0.055 **	-0.070	0.000	0.015	0.015	0.055	0.095 ***	0.150	-0.023 **	-0.014	-0.037
Philippines	0.165 *	0.976 *	0.035	-0.018	-0.025	0.089	0.064	0.004	-0.015	-0.011	0.000	-0.122	-0.122	-0.008	0.068 ***	0.060
Singapore	0.319 *	0.942 *	-0.032	0.024	0.075 *	-0.080	-0.005	-0.032 **	0.064 *	0.032	-0.015	-0.051	-0.066	0.030 *	0.001	0.031
Sri-Lanka	0.412 *	0.898 *	0.025	-0.009	0.002	-0.147 *	-0.145	-0.003	0.069 *	0.066	0.059	-0.060	-0.001	-0.026	0.043 ***	0.017
Taiwan	0.293 *	0.933 *	-0.057	0.027 *	-0.099 *	0.060	-0.039	0.134 *	0.128 **	0.262	-0.037	-0.244	-0.281	0.111 ***	0.197 ***	0.308
Thailand	0.191 *	0.978 *	-0.018	0.015 ***	-0.021	-0.184 **	-0.205	0.013 ***	0.033 ***	0.046	0.037	0.225 **	0.262	-0.024	-0.011	-0.035
Latin America																
Argentina	0.245 *	0.955 *	0.007	-0.014	0.025	-0.127 *	-0.102	-0.014 **	0.021 ***	0.007	0.001	0.127 **	0.128	-0.02 ***	0.021 ***	0.004
Brazil	0.377 *	0.881 *	0.013	0.020	0.010	-0.051	-0.041	0.014	0.039 ***	0.053	0.036	0.035	0.071	-0.04 **	-0.01	-0.050
Chile	0.332 *	0.918 *	-0.058	0.033	-0.076	0.276 *	0.200	0.015	-0.078 *	-0.063	0.073 *	-0.13 *	-0.060	-0.02 ***	0.052 *	0.033
Colombia	0.498 *	0.578 *	0.076 **	-0.160 *	0.014	-0.006	0.008	-0.066 **	0.038 ***	-0.028	0.051	-0.04	0.016	-0.02 ***	0.022	0.007
Ecuador	0.775 *	0.791 *	0.003	-0.001	0.059	0.742 *	0.801	-0.031	-0.323	-0.354	-0.18 **	0.512 *	0.328	0.352 *	-0.01	0.346
Mexico	0.402 *	0.714 *	-0.156 **	-0.165	-0.029	0.138	0.109	0.032	0.039	0.071	-0.02	-0.13	-0.157	0.015	0.043	0.058
Peru	0.322 *	0.931 *	0.002	0.021	-0.003	-0.040 ***	-0.043	0.011	0.026 **	0.037	0.059 **	-0.02	0.040	-0.02	0.007	-0.017
Venezuela	0.633 *	0.631 *	0.031	-0.027	-0.001	0.024	0.023	-0.009	0.007	-0.002	0.022	-0.04	-0.017	-0.02 ***	0.034	0.015

Notes: *, **, and *** denote significance at the 1%, 5% and 10% levels respectively. Standard errors (S.E.) are calculated using the quasi-maximum likelihood method of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals. The covariance stationarity condition is satisfied for the models, with all eigenvalues of $A \otimes A + G \otimes G$ less than one in modulus.

Table 4.2

Parameter estimates for variance-covariance equations: Emerging Europe and Middle East

	Local markets										Regional markets					
	a_{11}	g_{11}	a_{21}	g_{21}	a_{31}	a_{31d}	$a_{31}+a_{31d}$	g_{31}	g_{31d}	$g_{31}+g_{31d}$	a_{32}	a_{32d}	$a_{32}+a_{32d}$	g_{32}	g_{32d}	$g_{32}+g_{32d}$
Emerging Europe																
Bulgaria	0.354 *	0.936 *	-0.014	0.027 **	-0.094 *	0.033	-0.061	0.043 *	-0.032	0.011	0.080	0.052	0.132	0.000	0.129 *	0.129
Croatia	0.382 *	0.885 *	0.119 *	-0.071 *	0.031	0.029	0.060	-0.034 *	0.020	-0.014	0.053 **	-0.09 **	-0.039	-0.022 ***	0.055 *	0.033
Czech Republic	0.442 *	0.840 *	0.210 *	-0.102 *	0.100 *	0.193 *	0.293	-0.067 *	0.020	-0.047	0.086 *	-0.204 *	-0.118	-0.013 *	0.048 *	0.035
Estonia	0.353 *	0.929 *	0.048	0.036	0.029	0.068	0.097	-0.038 *	-0.027	-0.065	-0.047	-0.035	-0.082	0.053	0.236 **	0.289
Hungary	0.397 *	0.839 *	0.087 **	-0.055 *	0.026	-0.042	-0.016	-0.023 ***	0.047 **	0.024	0.066 *	-0.014	0.052	-0.019 *	0.016	-0.003
Israel	0.197 *	0.974 *	0.120	-0.022	-0.076	0.543 *	0.467	0.049	0.103	0.152	-0.051	-0.108	-0.159	0.059	-0.001	0.058
Latvia	0.627 *	0.834 *	0.007	0.005	0.032 *	-0.043 **	-0.011	-0.015 *	0.034 *	0.019	0.081 *	-0.04 ***	0.040	-0.027 *	0.034 **	0.007
Poland	0.292 *	0.931 *	0.019	-0.042	-0.032	0.004	-0.028	0.001	0.000	0.001	0.059 ***	-0.087	-0.028	-0.028 *	0.078 **	0.050
Romania	0.443 *	0.887 *	-0.022	0.028	0.007	0.063 ***	0.070	0.000	-0.020 ***	-0.020	0.099 *	-0.137 *	-0.038	-0.018 ***	0.052 *	0.034
Russia	0.370 *	0.915 *	0.017	-0.010	0.000	-0.201 ***	-0.201	0.003	0.012	0.015	-0.150 *	0.342 *	0.192	0.334	0.254 ***	0.588
Slovakia	0.546 *	0.552 *	0.116 **	-0.019	0.054	-0.164	-0.110	-0.027	0.079	0.052	0.079 *	-0.064 ***	0.015	-0.025 *	0.039 *	0.014
Slovenia	0.523 *	0.653 *	0.001	-0.110 **	0.025	-0.152	-0.127	0.022	0.342 *	0.364	-0.068	0.036	-0.032	0.029	0.139 *	0.168
South Africa	0.337 *	0.769 *	0.038	-0.084	0.028	0.101	0.129	-0.029	-0.001	-0.030	0.055	-0.147	-0.092	-0.025 **	0.071 *	0.046
Turkey	0.222 *	0.973 *	0.036 ***	-0.008 **	0.059 *	-0.136	-0.077	-0.010 ***	0.029 ***	0.019	-0.001	0.117 **	0.116	-0.007	0.022	0.015
Middle East and North Africa																
Egypt	-0.382 *	-0.205	-0.034 ***	-0.109 **	-0.037	-0.218 *	-0.255	-0.251	-0.549 **	-0.800	-0.077	0.083	0.006	0.026	-0.014	0.012
Jordan	0.492 *	0.551 *	0.075	0.043	0.031	0.509	0.540	-0.088	-0.778	-0.866	-0.079	-0.229	-0.308	0.066	0.543	0.609
Kuwait	0.435 *	0.777 *	0.003	0.069	-0.027	-1.511 *	-1.538	0.051	0.929 *	0.980	-0.102 *	0.568 *	0.466	0.051	-0.274	-0.223
Lebanon	0.716 *	0.455 *	0.019	0.040	0.062 **	-0.701 *	-0.639	-0.049	0.760 *	0.711	-0.069	0.003	-0.066	0.054 ***	-0.086	-0.032
Morocco	0.499 *	0.122	0.120 **	-0.098	0.097 **	0.197	0.294	0.101	1.027 **	1.128	-0.085 *	0.027	-0.058	0.042	0.006	0.048
Saudi Arabia	0.432 **	-0.888 *	0.068	-0.095 **	-0.026	0.108	0.082	0.025	0.010	0.035	-0.099 ***	-0.263 **	-0.362	-0.285 *	0.595 *	0.310
Tunisia	0.674 *	0.477 *	-0.046	-0.020	0.389 *	-0.415	-0.026	0.547 *	1.468 *	2.015	-0.036	0.196	0.160	0.151 *	0.007	0.158

Notes: *, **, and *** denote significance at the 1%, 5% and 10% levels respectively. Standard errors (S.E.) are calculated using the quasi-maximum likelihood method of Bollerslev and Wooldridge (1992), which is robust to the distribution of the underlying residuals. The covariance stationarity condition is satisfied for the models, with all eigenvalues of $A \otimes A + G \otimes G$ less than one in modulus.

Table 5
Likelihood ratio tests of restrictions on spillover parameters

	Local markets				Regional markets		
	H01: $a_{31}=a_{31d}=g_{31}=g_{31d}=0$	H02: $a_{31d}=g_{31d}=0$	H03: $a_{31}=g_{31}=0$	H04: $a_{21}=g_{21}=0$	H05: $a_{32}=a_{32d}=g_{32}=g_{32d}=0$	H06: $a_{32d}=g_{32d}=0$	H07: $a_{32}=g_{32}=0$
Emerging Asia							
China	1.780	39.756 *	1.324	33.790 *	37.764 *	33.742 *	9.882 *
Hong Kong	11.150 **	26.872 *	6.672 **	5.550 ***	7.326	3.496	3.314
India	52.206 *	2.948	6.090 **	7.276 **	13.206 **	12.342 *	1.200 *
Indonesia	10.846 **	3.588	6.130 **	13.480 *	98.378 *	7.618 **	10.938 *
Korea	21.106 *	13.044 *	55.860 *	46.880 *	25.462 *	46.280 *	1.928
Malaysia	81.752 *	16.754 *	24.182 *	12.806 *	0.082	4.988 ***	25.210 *
Pakistan	26.966 *	4.330	1.216	20.040 *	7.026	4.130	3.486
Philippines	6.830	2.372	1.632	0.930	3.096	2.468	0.366
Singapore	11.786 **	7.012 **	6.684 **	3.602	19.884 *	1.240	5.124 ***
Sri-Lanka	11.406 **	10.240 *	0.498	1.662	89.932 *	4.430	2.492
Taiwan	43.300 *	12.682 *	80.258 *	12.884 *	13.854 *	6.516 **	10.910 *
Thailand	10.316 **	9.580 *	4.498	2.980	11.980 **	10.954 *	1.660
Latin America							
Argentina	17.862 *	11.848 *	8.566 **	8.268 **	21.246 *	18.530 *	8.602 **
Brazil	12.828 **	7.302 **	2.208	8.706 **	9.608 **	0.286	9.458 ***
Chile	19.294 *	18.268 *	2.830	0.522	21.604 *	16.946 *	9.560 *
Colombia	14.566 *	2.556	10.464 *	18.435 *	5.166	2.352	4.298
Ecuador	14.082 *	74.614 *	49.338 *	43.456 *	41.424 *	21.296 *	14.796 *
Mexico	27.232 *	38.262 *	0.378	20.206 *	12.818 *	25.952 *	0.410
Peru	13.832 *	5.212 ***	2.534	7.292 **	9.696 **	0.564	9.382 *
Venezuela	1.574	1.330	0.606	0.461	7.842 ***	3.526	4.446
Emerging Europe							
Bulgaria	50.094 *	2.072	19.348 *	43.402 *	28.930 *	24.092 *	49.354 *
Croatia	24.287 *	18.668 *	61.180 *	9.223 *	12.067 *	0.176	1.672
Czech Republic	49.702 *	32.996 *	25.770 *	42.770 *	39.600 *	37.404 *	17.722 *
Estonia	10.805 **	1.646	13.786 *	11.185 *	38.234 *	2.011	11.649 *
Hungary	12.100 **	11.439 *	3.450	9.999 *	21.110 *	92.354 *	20.409 *
Israel	1.011	5.804 ***	2.531	2.073	8.594 ***	5.954 **	3.120
Latvia	16.987 *	6.193 **	91.493 *	35.319 *	23.503 *	7.801 **	74.805 *
Poland	3.067	0.012	2.737	10.602 *	69.743 *	14.246 *	11.722 *
Romania	6.028	0.750	0.984	6.644 **	23.682 *	13.370 *	13.748 *
Russia	13.393 *	13.309 *	0.110	1.738	10.543 **	14.532 *	8.265 **
Slovakia	7.836 ***	5.720 ***	2.690	8.408 **	20.366 *	10.072 *	23.324 *
Slovenia	28.327 *	37.146 *	1.851	10.898 *	16.188 *	12.629 *	1.930
South Africa	4.288	3.291	0.313	2.899	14.373 *	9.584 *	6.089 **
Turkey	20.014 *	123.378 *	18.927 *	7.746 **	127.490 *	124.630 *	126.323 *
Middle East and North Africa							
Egypt	1.774	18.340 *	7.974 ***	23.660 *	4.986	23.478 *	6.514 **
Jordan	17.476 *	14.648 *	1.354	2.640	9.168 **	0.240	0.434
Kuwait	45.636 *	30.042 *	0.448	7.134 **	9.946 **	29.256 *	3.932
Lebanon	16.522 *	16.122 *	2.478	12.940 *	16.640 *	18.214 *	1.300
Morocco	1.952	9.288 *	38.216 *	4.758 ***	9.864 **	12.054 *	5.224 ***
Saudi Arabia	8.185 ***	27.809 *	20.044 *	17.256 *	7.208	9.962 *	32.704 *
Tunisia	23.603 *	4.673	17.813 *	1.838	23.601 *	10.287 *	16.691 *

Notes: The LR statistics are computed between the unrestricted and restricted models, where $LR = -2(L_R - L_U)$. Rejection of the null hypothesis at the 1%, 5% and 10% is denoted by *, **, and *** respectively. The chi-squared critical values at 1%, 5% and 10% for 4 degrees of freedom are 13.277, 9.488, and 7.779; and for 2 degrees of freedom are 9.210, 5.991, and 4.605.

Table 6
Tests of changes in EME conditional variances during turbulent episodes in mature markets

	H0: $s_{ntp} = s_{tp}$ H1: $s_{ntp} < s_{tp}$							
	Full sample : 1996-2008		Sub-sample: 2004-08		Sub-sample: 2000-03		Sub-sample: 1996-98	
	s_{tp} / s_{ntp}	Reject H0	s_{tp} / s_{ntp}	Reject H0	s_{tp} / s_{ntp}	Reject H0	s_{tp} / s_{ntp}	Reject H0
Emerging Asia								
China	1.049		1.729	**	1.077		0.711	
Hong Kong	1.411	**	2.131	*	1.000		1.545	***
India	0.894		1.412	***	0.579		0.879	
Indonesia	1.159		1.345		0.995		1.240	
Korea	1.095		1.607	**	0.980		1.034	
Malaysia	1.524	*	1.798	**	0.936		1.865	*
Pakistan	1.117		1.206		0.963		1.243	
Philippines	1.079		1.193		0.869		1.242	
Singapore	1.324	**	2.404	*	0.872		1.418	***
Sri-Lanka	0.791		0.447		0.744		1.743	**
Taiwan	1.135		1.392		0.874		1.272	
Thailand	0.930		1.168		0.802		0.972	
Latin America								
Argentina	1.212	***	0.940		1.123		1.435	***
Brazil	1.738	*	1.295		1.252		2.484	*
Chile	1.430	*	2.172	*	0.893		1.461	***
Colombia	1.154		1.586	**	0.915		1.037	
Ecuador	0.323		0.372		0.280		0.324	
Mexico	1.377	**	1.309		1.041		1.867	*
Peru	1.628	*	2.256	*	0.856		1.655	**
Venezuela	1.054		0.749		0.730		1.543	***
Emerging Europe								
Bulgaria	1.086		1.255		0.880		na	
Croatia	1.054		1.122		0.791		1.365	
Czech Republic	1.625	*	1.806	**	1.357		1.842	**
Estonia	1.759	*	1.306		0.965		2.554	*
Hungary	1.619	*	1.237		1.303		2.419	*
Israel	1.004		1.133		0.861		1.074	
Latvia	4.253	*	1.717	**	5.299	*	2.916	*
Poland	1.262	***	1.433	***	0.912		1.636	**
Romania	1.377	**	1.373		0.650		2.211	*
Russia	1.573	*	1.046		0.893		2.440	*
Slovakia	0.795		0.677		0.935		0.728	
Slovenia	1.388	**	1.871	*	1.384	***	1.242	
South Africa	1.431	*	1.270		1.186		2.039	*
Turkey	1.062		1.154		0.919		1.164	
Middle East and North Africa								
Egypt	0.982		0.973		0.991		0.975	
Jordan	1.075		0.956		1.245		1.090	
Kuwait	1.007		0.902		1.357		0.803	
Lebanon	0.668		0.526		0.896		0.586	
Morocco	1.000		1.028		1.066		0.882	
Saudi Arabia	1.441	**	1.865	*	1.179		0.771	
Tunisia	1.175		0.871		1.159		1.823	***

Notes: s_{ntp} and s_{tp} indicate averages of the predicted conditional variances $h_{11,t}$ for non-turbulent periods and turbulent periods, respectively, in the full sample and the sub-samples. *,**, *** denote rejection of the null hypothesis at the 1%, 5%, and 10% levels. Degrees of freedom, and hence critical values of the F distribution, vary due to slight variations in the length of country samples.

Table 7
Tests of changes in conditional correlations between EME markets and mature markets during turbulent episodes in mature markets

	H0: $r_{ntp} \geq r_{tp}$											
	Full sample: 1996-2008			Sub-sample: 2004-08			Sub-sample: 2000-03			Sub-sample: 1996-98		
	r_{ntp}	r_{tp}	Reject H0:	r_{ntp}	r_{tp}	Reject H0:	r_{ntp}	r_{tp}	Reject H0:	r_{ntp}	r_{tp}	Reject H0:
Emerging Asia												
China	0.043	0.031		0.079	0.148		0.006	-0.074		0.040	0.047	
Hong Kong	0.605	0.592		0.579	0.602		0.690	0.723		0.552	0.401	
India	0.302	0.335		0.436	0.517		0.338	0.250		0.125	0.255	
Indonesia	0.326	0.340		0.488	0.534		0.141	0.152		0.332	0.390	
Korea	0.499	0.497		0.611	0.583		0.529	0.573		0.351	0.300	
Malaysia	0.343	0.391		0.401	0.530		0.284	0.390		0.338	0.242	
Pakistan	0.126	0.138		0.181	0.206		0.088	0.121		0.104	0.087	
Philippines	0.376	0.391		0.478	0.560		0.314	0.270		0.327	0.377	
Singapore	0.503	0.557		0.623	0.691		0.518	0.604		0.362	0.348	
Sri-Lanka	0.019	0.081		-0.042	0.146		0.030	0.003		0.073	0.118	
Taiwan	0.343	0.477	***	0.281	0.416		0.417	0.552		0.337	0.440	
Thailand	0.381	0.467		0.371	0.580	***	0.444	0.431		0.331	0.395	
Latin America												
Argentina	0.435	0.504		0.536	0.746	**	0.324	0.298		0.434	0.526	
Brazil	0.572	0.596		0.637	0.721		0.527	0.562		0.547	0.508	
Chile	0.380	0.450		0.441	0.547		0.368	0.429		0.327	0.376	
Colombia	0.198	0.244		0.284	0.322		0.137	0.151		0.166	0.289	
Ecuador	-0.033	-0.063		-0.038	-0.030		-0.055	-0.159		-0.008	0.032	
Mexico	0.628	0.666		0.676	0.695		0.604	0.698		0.600	0.593	
Peru	0.256	0.437	**	0.270	0.619	**	0.272	0.341		0.225	0.374	
Venezuela	0.192	0.234		0.207	0.250		0.173	0.166		0.195	0.310	
Emerging Europe												
Bulgaria	0.008	0.000		0.034	0.020		-0.032	-0.015		na	na	
Croatia	0.258	0.297		0.133	0.217		0.300	0.361		0.382	0.293	
Czech Republic	0.350	0.620	*	0.426	0.703	**	0.352	0.645	**	0.258	0.466	
Estonia	0.253	0.343		0.370	0.364		0.257	0.389		0.111	0.239	
Hungary	0.458	0.556		0.508	0.591		0.425	0.578		0.435	0.472	
Israel	0.440	0.658	*	0.404	0.652	**	0.453	0.682	**	0.468	0.624	
Latvia	0.124	0.283	***	0.114	0.266		0.136	0.278		0.122	0.313	
Poland	0.469	0.590	***	0.548	0.620		0.448	0.632	***	0.397	0.479	
Romania	0.085	0.249	***	0.166	0.491	**	-0.001	0.023		0.079	0.319	
Russia	0.373	0.405		0.424	0.594		0.411	0.422		0.273	0.127	
Slovakia	0.023	-0.062		-0.002	-0.073		0.053	-0.104		0.022	0.024	
Slovenia	0.103	0.241		0.098	0.249		0.081	0.256		0.132	0.207	
South Africa	0.583	0.632		0.671	0.662		0.540	0.603		0.526	0.642	
Turkey	0.340	0.438		0.399	0.661	**	0.283	0.318		0.331	0.346	
Middle East and North Africa												
Egypt	0.130	0.195		0.145	0.184		0.118	0.224		0.126	0.168	
Jordan	0.073	-0.088		0.068	-0.115		0.072	-0.040		0.080	-0.124	
Kuwait	-0.021	0.111		-0.021	0.039		-0.035	0.136		-0.007	0.155	
Lebanon	0.088	0.191		0.115	0.148		0.057	0.168		0.089	0.269	
Morocco	0.063	0.125		0.087	0.149		0.041	0.129		0.059	0.095	
Saudi Arabia	0.030	0.003		0.023	-0.047		0.040	0.029		0.024	0.037	
Tunisia	0.098	0.161		0.100	0.123		0.118	0.207		0.052	0.115	

Notes: r_{ntp} and r_{tp} indicate the average conditional correlation coefficients for non-turbulent periods and turbulent periods, respectively, in the full sample and the sub-samples. *,**, *** denote rejection of the one-tail tests of the null hypothesis at the 1%, 5%, and 10% levels. Tests are based on the Fisher transformation of the conditional correlation coefficients, whose distribution is approximately normal with the mean 1/2*[ln ((1 + r)/(1-r))] and the variance 1/(n - 3).