

Testing Financial Contagion with Time-Varying Correlation of Heteroscedastic Asset Returns

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Abstract

We suggest that there is a significant time-varying relationship between cross-market co-movements and predictable market volatility. We demonstrate that the time-varying component of cross-market correlation is attributable to the responses by rational risk-averse investors who systematically revise their expectations in response to changing market volatility. Our results from the time-varying conditional correlation test for contagion show that (a) only the Philippines or the Philippines and Italy show evidence of contagion from the 1997 Asian crisis, and (b) there is no contagion evidence from both the 1994 Mexican peso crisis and 1987 U.S. stock market crash.

JEL Classifications: C32, F30, G15

Keywords: Financial contagion; cross-market co-movement; time-varying correlation test; cross-market correlation; modified DCC model

1. Introduction

With the growing importance of the role of international financial linkage, many studies have investigated the impact of a financial crisis in one region on the financial systems in other regions. In particular, recent financial crises have spawned empirical inquiries on the nature and impact of international equity market contagion. These studies have focused on the sharp increase in market co-movements that occur after an extremely negative return shock in one country.

We suggest that the substantial portion of cross market co-movements is induced by the reactions of rational, risk-averse investors who systematically revise their expectations along with the intertemporal risk-return relation to changing market volatility through various financial linkages. Unlike those previous studies that view the time-varying volatility as causing a heteroscedasticity bias in the correlation test for contagion, we suggest that the time-varying volatility is indeed a fundamental factor inducing the cross-market co-movements. However, the traditional correlation test for contagion ignores incorporating the time-varying aspect of cross-market co-movements.

Postulating that international equity market investors revise their expectations in response to the changing market volatility of other equity markets through many different financial channels, we propose a time-varying conditional correlation test for international equity market contagion. The new test is based on the fact that the time-varying nature of cross-market correlation is attributable to the responses of risk-averse investors who systematically revise their expectation in responding to time-varying volatility. In this new time-varying correlation test, we model cross-market conditional correlation as a function of time-varying volatility between two markets, such that contagion is defined as a sudden, sharp increase (or structural break) in the dynamics of time-varying conditional correlation during a crisis period. Thus, we do not view any temporal changes in correlation dynamics as contagion evidence.

To model time-varying cross-market correlations, we employ the dynamic conditional correlation (DCC) model proposed by Engle (2002) and Engle and Sheppard (2001). The main feature of the DCC model is that it allows the dynamics of conditional correlation to evolve from the cross-product of market volatilities and its own autoregressive process which captures the time-varying components of cross-market co-movements. This time-varying component of the conditional correlation is supposed to capture risk-averse investors' rational responses to changing market volatility.

Using a DCC multivariate GARCH model, we re-examined contagion for the 1997 Asian market crisis, the 1994 Mexican peso crisis, and the 1987 U.S. stock market crash. Contagion in our test is defined as a structural break in the dynamics of the conditional correlation during the crisis period. We found that the number of contagion events reported by the conventional constant correlation test significantly decreases in our time-varying conditional correlation test. For the 1997 Asian crisis, for example, out of the 16 countries reporting contagion evidence with the constant correlation test, only two countries, the Philippines and Italy, exhibit contagion evidence in our time-varying conditional correlation test for daily returns. For the two-day rolling average returns case, our test results show contagion occurs only in the Philippines data.

For the 1994 Mexican peso crisis, of the 2 countries (4 countries for the two-day moving average returns) reporting evidence of contagion by the constant correlation test, none exhibit contagion in our time-varying conditional correlation test. For the 1987 U.S. market crash, of the 4 countries (6 countries for the two-day moving average returns) reporting evidence of contagion by the conventional constant correlation test, none exhibit contagion evidence in our time-varying conditional correlation test. We also performed robustness checks using returns based on local currencies, and found the results robust.

Our test results confirm: (a) cross-market correlations are significant and change over time, reflecting the time-varying components of cross-market co-movements, (b) the main source of time-

varying correlation is the systematic responses by risk-averse investors who systematically revise and adjust their expectations due to changing volatility, (c) when the time-varying feature of the conditional correlation is presented, contagion evidence mostly disappears, and (d) a high correlation during the crisis period reported as contagion evidence by the constant correlation test is mostly attributable to the high level of cross-market co-movements induced by the rational risk-averse investors during the crisis period.

Finally, our time-varying correlation test resolves the statistical bias problem in the conventional correlation test pointed out by Forbes and Rigobon (2002), Loretan and English (2000), and Boyer, Gibson, and Loretan (1999). In the conventional correlation test for contagion, heteroscedasticity in asset returns is viewed as a bias causing return correlation to be spuriously inflated and leading to an inaccurate test for contagion. However, in our correlation test for financial contagion, time-varying volatility plays an important role as an underlying force to drive the time-varying cross market correlation, such that the time-varying nature of the cross market correlation is incorporated into the dynamics of the conditional correlation. Thus, with this time-varying nature of the volatility-correlation relation correctly specified in the test of contagion, our time-varying correlation test effectively avoids the statistical bias problem raised by the previous studies.

The rest of this paper is organized as follows. In section 2, we discuss the related literature. In section 3, we describe the DCC multivariate GARCH model and specify the modified DCC model to capture a structural break in the dynamics of time-varying conditional correlation. Section 4 presents empirical results and interpretations for testing the 1997 Asian crisis, and section 5 reports empirical results for the test of the 1994 Mexican peso crisis and the 1987 U.S. market crash. Section 6 concludes the paper with a brief summary.

2. Related Literature

There are many theoretical explanations of financial contagion. Most of these studies either interpret excess co-movement as an equilibrium result of fully rational behavior of agents in market setting with frictions (such as information asymmetry, information heterogeneity, imperfect competition, wealth and borrowing constraints, risk-bearing capacity, etc) or attribute excess co-movement to irrational decision-making by those same agents (such as herding, categorization, preferred habitat, etc).

For example, Valdes (1996) suggested that, since a crisis in one country can reduce the liquidity of market participants, investors may be forced to sell assets in another market to rebalance their portfolios in order to satisfy margin calls or to meet regulatory requirements. Masson (1999) showed that small triggers in one country can act as precipitating factors that induce a coordination of negative investor expectations about the market equilibrium for other countries. Mullainathan (2002) claimed that investors imperfectly recall past events, so a crisis in one country could trigger memories of past crises, causing investors to re-compute their priors on variables such as debt default, and assign higher probabilities to bad states. Demonstrating that cross-market rebalancing and information asymmetry can be the root of financial contagion, Kodres and Pritsker (2002) suggested that cross-market portfolio rebalancing may be a contagion channel. Yuan (2005) showed that correlated price movements arise from the interaction of information asymmetry and borrowing constraints. Kyle and Xiong (2001) and Gromb and Vayanos (2002) argued that contagion could occur when financial intermediaries suffer unfavorable shocks to their portfolio positions, such that their portfolio values fall as does their risk bearing ability. Broner, Gelos, and Reinhart (2006) presented a model of investor portfolio rebalancing away from overexposed countries which could act as a crisis transmission channel.

The empirical literature on financial contagion has focused on the excess co-movement beyond the degree that is justified by economic fundamental. The correlation test has been widely used as a conventional methodology for testing financial contagion by examining whether cross-market correlations increase significantly after a crisis in a single country.¹ King and Wadhvani (1990) was the first study to employ this correlation approach in examining cross-market co-movements. They found that the correlation between the London and the New York stock markets rose immediately after the 1987 U.S. market crash, but returned to pre-crash levels when the volatility fell. Calvo and Reinhart (1996) suggested that the 1994 Mexican crisis was contagious because return correlations of weekly stock and Brady bonds for Asian and Latin American emerging markets increased after the Mexican peso's collapse. Baig and Goldfajn (1998) examined five East Asian countries during the 1997 Asian crisis period, and found that the cross-market correlations for stock indices, currencies, interest rates, and sovereign spreads, increased significantly during the crisis. Examining contagion in the context of asset pricing models, Wongswan (2003) and Bekaert, Harvey and Ng (2005) found that the correlations between idiosyncratic shocks are excessive from an asset pricing perspective. Park and Song (2001) and Chakrabarti and Roll (2002) also found that stock market co-movements in the East Asian region became larger during the crisis.

In the traditional correlation test, financial contagion is defined as a significant increase in cross-market co-movement during crises time periods relative to tranquil periods. This definition of contagion is popular for two reasons. First, it is intuitively appealing. If shocks are transmitted because two countries are fundamentally related, then after controlling for the macroeconomic fundamentals and the global shocks, there is little reason for the return correlation to increase during a market crisis, although the magnitudes of the transmitted shocks may be large. Second, this definition makes it easy to implement

¹ See Forbes and Rigobon (2002) for the definition of equity market contagion and interdependence.

a test for contagion by examining whether the cross-market correlations are statistically different for two periods, the stable period and the crisis period. In this paper, we also adopt this definition of financial contagion for our analysis.

The traditional correlation test for contagion has been challenged by several studies. Forbes and Rigobon (2002), Loretan and English (2000), and Boyer, Gibson, and Loretan (1999) argued that the traditional correlation test for contagion is considerably biased due to the heteroscedasticity in the asset returns. On statistical grounds, they showed that return correlations can spuriously increase when stock markets become more volatile. Specifically, proposing a statistical adjustment for the heteroscedasticity bias in the correlation measure, Forbes and Rigobon (2002) showed that the previous result of contagion is reversed dramatically once the conditional correlation is adjusted for the bias in the test.²

Recently, however, Bartram and Wang (2005) and Corsetti, Pericoli, and Sbracia (2005) raised an issue with Forbes and Rigobon's (2002) adjustment for the heteroscedasticity bias. They pointed out that Forbes and Rigobon's empirical finding relies heavily on their particular assumptions about the stochastic process of idiosyncratic shocks, so that Forbes and Rigobon's adjustment may cause the correlation test to be severely biased towards the null hypothesis of no contagion. On the other hand, several other recent studies have found evidence of contagion during recent crises after correctly adjusting the estimated correlation for the heteroscedasticity bias. For example, by correcting three types of bias that they assumed affect the contagion tests, Caporale, Cipollini and Spagnolo (2005) showed contagion evidence during the 1997 Asian crisis. Measuring exceedence correlations from the extreme value theory, Bae, Karolyi and Stulz (2003) and Boyer, Kumagai and Yuan (2005) also found evidence of contagion during the Asian

² Forbes and Rigobon (2002) showed that, when the bias is adjusted in the correlation tests, there is virtually no evidence of contagion over a set of 27 countries during the 1997 Hong Kong stock market crisis, 1994 Mexican peso devaluation, and 1987 U.S. stock market crash.

crisis. More recently, using copulas with Markov switching models to measure cross-market dependence during the Asian crisis, Rodriguez (2007) found significant evidence of contagion.

Another category of research has attempted to measure excess co-movement in a fashion which is consistent, at least in its principles, to the definition of financial contagion. For example, Pyndick and Rotemberg (1990, 1993), Bekaert, Harvey, and Ng (2005), Bekaert, Hodrick, and Zhang (2008), and Kallberg and Pasquariello (2008) attempt to measure co-movement in asset prices beyond what could be explained by common factors such as inflation, aggregate demand, foreign exchange or interest rates, and other fundamentals which should be expected to affect asset's payoffs at liquidity.

On the other hand, many recent studies have documented that the international equity market correlations are not constant, but time-varying. For example, Longin and Solnik (1995) showed that for seven OECD countries over the thirty-year period 1960-1990, correlations between U.S. and other OECD countries increased over time. They also found that the return correlation rises for the time periods when the market volatility is high. Ramchand and Susmel (1998) confirmed Longin and Solnik's (1995) findings of changing cross-market correlations with more recent data. Karolyi and Stulz (1996) showed that the correlation between the U.S. and Japanese stocks is high when there are large return shocks to the markets. Longin and Solnik (2001) and Ang and Chen (2002) also showed that the correlation increases only in periods of market downturns, and is not related to the market volatility of the bullish market. The common results from these studies are that correlation changes over time, and there is a significant relationship between cross market correlation and time-varying volatility.

Therefore, time-varying volatility plays an important role in the cross market co-movements, as substantial amount of cross market co-movements is induced by the responses of international equity market investors to the changes in predictable volatility. This implies that time-varying volatility should be considered as a fundamental economic factor inducing time-varying cross market correlation other

than as a noise factor causing a statistical bias in the correlation test for contagion. Thus, the nature of the international equity market investors' response to the changing volatility could be explained by two widely used hypotheses in finance, the time-varying rational expectation hypothesis and the stock market overreaction (psychology) hypothesis.³

The time-varying rational expectation hypothesis assumes that risk-averse investors revise their expectations in response to changing market volatility. This implies that, given the risk-return tradeoff relationship, investors require a higher risk premium for a higher level of *perceived* future volatility [see Fama and French (1988), Ball and Kothari (1989), and Cecchetti, Lam and Mark (1990)]. In contrast, the stock market overreaction hypothesis argues that investors tend to overreact to any market news, with extremely optimistic or pessimistic expectations [see Shiller (1984), Summers (1986), Poterba and Summers (1988), DeBondt and Thaler (1985, 1987), Lehmann (1990), and Lo and MacKinlay (1990)].

These two hypotheses are not mutually exclusive in generating international equity market co-movements, as cross-market co-movements are attributable not only to intertemporal risk-return relation but also to investor overreaction with extremely optimistic or pessimistic expectations. We concentrate on the role of the two hypotheses in the correlation test for contagion by focusing on how the cross-market co-movements induced by risk-averse investors' rational responses differ from those induced by investors' overreactions to changing market volatility. This approach is based upon a different view from that of previous studies, which focuses on a statistical bias of time-varying volatility, but it provides a more reasonable economic rationale for the explanation of cross-market correlation.

³ The two hypotheses have been used as competing explanations on the predictable variation in stock returns. For the mean reverting behavior of stock prices explored initially by Summers (1986), for example, the time-varying rational expectation hypothesis argues that the mean reversion in the stock price is attributed to the adjustment of risk premium by risk-averse investors to changing market volatility. In contrast, the stock market overreaction hypothesis interprets the reverting behavior of stock prices as evidence of stock market inefficiency. It argues that the temporary long swings of the stock price away from its fundamental value is a result of stock market overreaction with irrational expectations to waves of optimism and pessimism, thereby rejecting the random walk process of stock price.

3. The Model

Our modeling strategy is (a) to capture the time-varying nature of the conditional correlation and (b) to capture a structural break in the dynamics of the conditional correlation during the crisis period. As a base model, we use the dynamic conditional correlation (DCC) model proposed by Engle (2002), which captures the time-varying component of correlation dynamics induced by the cross-product of conditional variances and its own autoregressive process. In our time-varying conditional correlation test, contagion is defined as a statistically significant structural break in the correlation dynamics during the crisis periods. To examine contagion, we specify two modified DCC multivariate GARCH models, with a time dummy variable imposed for representing the turmoil periods.

3.1. The Dynamic Conditional Correlation Multivariate GARCH Model

Typical problems in the estimation of multivariate GARCH models mostly involve the computational difficulties associated with the number of parameters to be estimated and the assurance of positive definiteness of the estimated conditional covariance matrix. Since the introduction of the multivariate ARCH model by Kraft and Engle (1982), many studies have suggested various model specifications for resolving the problems arising in estimation. Among them are the diagonal-*vech* model by Bollerslev et al. (1988) and the BEKK model by Baba, Engle, Kraft, and Kroner (1990).

However, these early specifications did not completely resolve the mentioned problems. For example, while the diagonal-*vech* model by Bollerslev et al. (1988) reduces the number of parameters to be estimated, it is still computationally not feasible when the number of the time-series is greater than five, with no assurance that the estimated covariance matrix is positive definite for all realizations. Even with

its capability to ensure the positive definiteness of the covariance matrix, the BEKK model by Baba et al. (1990) still suffers from a difficulty in the exact interpretation of the individual coefficients.

In contrast, the Constant Conditional Correlation (CCC) model by Bollerslev (1990) is relatively safer than the other two models in the sense that the assumption of constant correlation reduces computational complexity and the number of parameters to be estimated, and it guarantees the positive definiteness of the covariance matrix.⁴ Due to these attractive features, the CCC model has been used in many empirical applications.

Although Bollerslev's (1990) test for constant correlation accepts the null of constant correlation, the formal tests developed by Tse (2000) and Bera and Kim (2002) both reject the null of constant correlation for certain types of asset returns, notably for the national stock index returns. This motivated an extension of the CCC model to the dynamic conditional correlation (DCC) models by Engle (2002) and Engle and Sheppard (2001).

The DCC model assumes that the correlation matrix of the normalized residuals is time-varying. One of the critical merits of the DCC model lies in its simplicity of estimation with the two-stage estimation method. The first stage involves estimating univariate GARCH models for each series. Using the normalized residuals estimated from the first stage, the second stage involves estimating a conditional correlation matrix. The two-stage estimation method dramatically reduces the number of parameters to be estimated using maximum likelihood.

The DCC multivariate GARCH process of returns, r_t , from N different return series is:

⁴ With the time-invariant correlation matrix, the CCC model implies that the temporal variation in conditional covariance is determined solely by the time-varying conditional variance process. If the conditional variance process takes all positive values, and the conditional correlation matrix is positive definite, then the conditional covariance matrix is guaranteed to be positive definite.

$$r_t = E(r_t | \Omega_{t-1}) + \varepsilon_t, \quad \varepsilon_t | \Omega_{t-1} \sim N(0, H_t) \quad (1)$$

$$H_t = D_t R_t D_t, \quad (2)$$

where Ω_{t-1} is the set of information available up to time $t-1$; ε_t is the vector of innovations that is assumed to be conditionally multivariate normal with zero mean and time-varying conditional covariance matrix H_t ; R_t is the time-varying conditional correlation matrix; and D_t is the $N \times N$ diagonal matrix of the conditional standard deviation, $\sqrt{h_{it}}$, on the i^{th} diagonal. The elements of the volatility matrix D_t are assumed to be the following GARCH model:

$$h_{it} = \kappa_i + \sum_{s=1}^p \alpha_{is} \varepsilon_{it-s}^2 + \sum_{s=1}^q \beta_{is} h_{it-s} \quad (3)$$

We consider the following DCC model:

$$Q_t = (1 - \sum_{r=1}^R \delta_r - \sum_{s=1}^S \gamma_s) \bar{Q} + \sum_{r=1}^R \delta_r Q_{t-r} + \sum_{s=1}^S \gamma_s (v_{t-s} v_{t-s}') \quad (4)$$

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1},$$

where \bar{Q} is the unconditional covariance matrix of the standardized residual vector v_t from the first stage estimation, and Q_t^* is the diagonal matrix composed of the square root of the diagonal elements of Q_t . \bar{Q} is constrained such that the long-run covariance matrix is the sample covariance matrix and is replaced with the sample analogue, $T^{-1} \sum_{i=1}^T v_i v_i'$. Engle and Sheppard (2001) show that for Q_t to be

positive definite, δ 's and γ 's should be non-negative with $\sum_{r=1}^R \delta_r + \sum_{s=1}^S \gamma_s < 1$. R_t is also positive definite

when Q_t is positive definite.

The log likelihood function for the estimation of parameters can be specified as follow:

$$\begin{aligned}
L(\theta) &= -\frac{TN}{2} \log 2\pi - \frac{1}{2} \sum_{t=1}^T (\log |H_t| - \varepsilon_t' H_t^{-1} \varepsilon_t) \\
&= -\frac{TN}{2} \log 2\pi - \frac{1}{2} \sum_{t=1}^T (\log |D_t R_t D_t| - \varepsilon_t' D_t^{-1} R_t^{-1} D_t^{-1} \varepsilon_t) \\
&= -\frac{TN}{2} \log 2\pi - \frac{1}{2} \sum_{t=1}^T (2 \log |D_t| + \log |R_t| - v_t' R_t^{-1} v_t).
\end{aligned} \tag{5}$$

3.2. Empirical Models for the Test of Contagion

We specify the following DCC (1,1) multivariate GARCH model as a base model to capture the time-varying component of the conditional correlation:

Model 1: DCC model

$$\begin{aligned}
r_{jt} &= \mu_j + \rho r_{j,t-1} + a_j i_{jt} + b_j i_{US,t} + \varepsilon_{jt}, \\
h_{jt} &= \kappa_j + \alpha_j \varepsilon_{jt-1}^2 + \beta_j h_{j,t-1}, \\
Q_t &= (1 - \delta - \gamma) \bar{Q} + \delta Q_{t-1} + \gamma (v_{t-1} v_{t-1}'),
\end{aligned} \tag{6}$$

where j is the country other than the crisis country, and r_{jt} is the return of country j . i_{jt} is the short-term interest rate of country j , and $i_{US,t}$ is the 3-month U.S. Treasury bill rate.⁵

To capture a structural change in the dynamics of the conditional correlation during the periods of turmoil, we specify the following modified DCC (1,1) multivariate GARCH model as model 2, with a crisis dummy variable added to capture a structural break in the autoregressive process of the conditional correlation.

Model 2: Modified DCC Model A

$$\begin{aligned}
 r_{jt} &= \mu_j + \rho r_{j,t-1} + a_j i_{jt} + b_j i_{US,t} + \varepsilon_{jt}, \\
 h_{jt} &= \kappa_j + \alpha_j \varepsilon_{jt-1}^2 + \beta_j h_{jt-1}, \\
 Q_t &= (1 - \delta - \delta^c D - \gamma) \bar{Q} + (\delta + \delta^c D) Q_{t-1} + \mathcal{W}_{t-1} v'_{t-1},
 \end{aligned} \tag{7}$$

where D is a dummy variable taking a value 1 for the crisis period, otherwise taking 0. δ^c is a smoothing crisis dummy parameter, which captures a shift in the time-varying conditional correlation, if any. The parameter restrictions for the positive definite covariance matrix are given by $\delta \geq 0$, $\delta^c \geq 0$, and $\delta + \delta^c + \gamma < 1$. Using model 2 as an unrestricted model, we performed the likelihood ratio (LR) test for contagion against model 1 (the base DCC model) for the null hypothesis of $H_0 : \delta^c = 0$. The test statistic is distributed as a χ^2 with one degree of freedom.

⁵ Several studies have employed different control variables. For example, Baig and Goldfajn (1998) used domestic news dummies to control for domestic fundamentals and the S&P 500 index returns and the yen-U.S. dollar exchange rate to control for global factors. Park and Song (2001) used the overnight call rate to control for domestic fundamentals and the S&P 500 index returns and the differential between the yen-U.S. dollar and own currency-U.S. dollar exchange rates to control for global factors. We also used the S&P 500 index returns as a control variable, and found the results were robust.

In order to capture a structural break in the dynamics of the conditional correlation more effectively, we estimate the following modified DCC (1,1) model as model 3. The only difference between model 2 and model 3 is that we add one more crisis dummy variable to the news impact term in addition to the autoregressive term.

Model 3: Modified DCC Model B

$$\begin{aligned}
r_{jt} &= \mu_j + \rho r_{j,t-1} + a_j i_{jt} + b_j i_{US,t} + \varepsilon_{jt}, \\
h_{jt} &= \kappa_j + \alpha_j \varepsilon_{jt-1}^2 + \beta_j h_{j,t-1}, \\
Q_t &= (1 - \delta - \delta^c D - \gamma - \gamma^c D) \bar{Q} + (\delta + \delta^c D) Q_{t-1} + (\gamma + \gamma^c D) v_{t-1} v'_{t-1},
\end{aligned} \tag{8}$$

where δ^c and γ^c are a smoothing crisis dummy parameter and a news impact crisis dummy parameter, respectively. A structural change in the time-varying conditional correlation, if any, can be captured by δ^c and γ^c . To ensure the positive definite covariance matrix, parameter restrictions are given by $\delta, \delta^c, \gamma, \gamma^c \geq 0$, and $\delta + \delta^c + \gamma + \gamma^c < 1$. In our proposed likelihood ratio tests for contagion, the above model 3 was tested against model 1 for the null hypothesis of $H_0 : \delta^c = \gamma^c = 0$. The LR test statistic is distributed as a χ^2 with two degrees of freedom.

4. Empirical Results and Interpretations

4.1. Data Description

The sample of countries for testing contagion from the 1997 Asian crisis includes 28 national stock markets: eleven markets from Asia, ten markets from Europe, and six markets from North and

South America. Using 28 daily national stock market indexes retrieved from the Datastream, we calculate daily percentage returns as logarithmic differences multiplied by 100. Returns are based on both local currencies and U.S. dollars. We employ the 3-month short-term interest rate as a proxy to capture the changes in domestic macroeconomic fundamentals and the aggregate monetary shocks for each country. A list of market indexes and short-term interest rates used in the analysis is reported in the Appendix.

For the 1997 Asian market crash, we test for contagion from Hong Kong to the rest of the world. While there is a sufficient agreement as to when a crisis started, there is more ambiguity and disagreement as to the ending date of the crisis. Following Forbes and Rigobon (2002), we apply a somewhat narrow crisis window to our test, given that the Hong Kong market lost about a quarter of its value in four trading days starting on October 17, 1997, and it continued to decline until the end of November. We thus define the crisis period for the 1997 Asian market crash as starting on October 17, 1997, and ending on November 14, 1997. We define the stable period as January 1, 1996, to October 16, 1997, such that the stable period is immediately followed by the one-month-long crisis period.⁶ Thus, the full period considered in our test is from January 1, 1996, to November 14, 1997.

On any given day, the Hong Kong market opens earlier than any other market in our sample, except for Australia, Japan, and Korea. Australia opens 2 hours earlier, and Japan and Korea open 1 hour earlier than Hong Kong. Major European markets such as France, Germany, Italy, and the Netherlands open 7 hours later, and the U.K. opens 8 hours later than Hong Kong. As the last, Wall Street opens 13

⁶ According to Forbes and Rigobon (2002), although the Thailand and Indonesian markets declined sharply in July and August 1997 respectively, the press in the U.S. and Europe paid little attention to the earlier movements in these markets until the sharp decline in the Hong Kong market in mid-October. After this, events in Asia became headline news, and an avid discussion quickly began on the East Asian “crisis” and possibility of “contagion” to the rest of the world. Thus, we tested for financial contagion from Hong Kong to the rest of the world during the Hong Kong market turmoil.

hours later than Hong Kong. Thus, we match the Hong Kong stock return at time t with the other countries' returns at time t for the 1997 Asian market crash.

For the 1994 Mexican peso crisis, the stable period is from January 1, 1993, to December 18, 1994, and the crisis period is from December 19, 1994, to December 31, 1994. For the 1987 U.S. market crash, the stable period is from January 1, 1986, to October 16, 1987, and the crisis period is from October 17, 1987, to December 4, 1987. If a country's stock market is open at the same time as the U.S. and Mexico markets, we match the country's index return at time t with the U.S. and Mexico index returns at time t ;⁷ otherwise, we match the country's index return at time t with the U.S. and Mexico index returns at time $t-1$.⁸

Following Forbes and Rigobon (2002) and Corsetti et al. (2005), we also employ two-day rolling-average returns of each country for the contagion test. While the use of the two-day moving average returns is effective in controlling the problem arising from the different time-zones of the national stock markets, the two-day return series exhibits a high degree of serial correlation for all countries. We remove serial correlations in the two-day rolling average returns by estimating AR(8) model for all series. After removing serial dependence, we estimate the DCC multivariate GARCH model on the resulting residuals.

Table I reports the summary statistics of both daily and two-day rolling-average return series for each country. It shows that both return series exhibit an excess kurtosis, and the *squared* returns are all strongly serially correlated. This indicates that all the index returns are characterized by the time-varying heteroscedasticity, which is known as a stylized fact of stock returns. As mentioned earlier, we view the time-varying heteroscedasticity of stock returns as one of the important economic factors to induce the time-varying conditional return correlation.

⁷ Canada and countries in Latin America belong to this category.

⁸ Countries in Asia and Europe belong to this category.

Insert Table 1 about here

4.2. Test for the 1997 Asian Market Crisis

4.2.1. Conventional Z-Tests for Contagion

The conventional test procedure conducted in this paper is as follows. First, we estimate the univariate GARCH (1,1) model of equation (6) for the entire period and obtain the residuals. Dividing the residuals into the stable and crisis periods, we compute the cross-market correlation coefficients between crisis country, c , and other country, j , for each of the two sample periods. To examine if the correlation coefficient of the crisis period is significantly greater than that of the stable period, the hypotheses of the test are specified as:

$$\begin{aligned} H_0 : \rho_{c,j}^{crisis} &\leq \rho_{c,j}^{stable} \\ H_1 : \rho_{c,j}^{crisis} &> \rho_{c,j}^{stable}. \end{aligned} \tag{9}$$

The test statistic can be obtained by considering the distribution of the sample correlation coefficient, which is approximately normal *only* when the population correlation is zero. When the sample correlation coefficient is other than zero, its distribution is highly skewed and not even normal for large samples [see Hays (1994)].⁹ With the Fisher's z -transformation, however, the following z -statistic can be derived for testing:

$$z = T(\hat{\rho}) = \frac{1}{2} \ln \frac{1 + \hat{\rho}}{1 - \hat{\rho}} \sim N \left[T(\rho), \frac{1}{n-3} \right], \tag{10}$$

⁹ When ρ is greater than zero, the distribution has a negative skew, with intervals of high values of r relatively more probable than similar intervals of low values.

where $T(\hat{\rho})$ is approximately Gaussian if the joint distribution of the samples is not too far from the bivariate normal, and the sample size, n , is not too small (e.g., $n \geq 20$).¹⁰ Since the variance of z is independent of the population correlation ρ , a very simple approach for statistical inferences is possible.

Thus, under the assumption that two samples are drawn from two independent bivariate normal distributions with the same population correlation, the distribution of the z -test statistic converges to a normal distribution with the following mean and variance:

$$z(\hat{\rho}^C) - z(\hat{\rho}^S) \sim N\left(0, \frac{1}{n^C - 3} + \frac{1}{n^S - 3}\right), \quad (11)$$

where n^C and n^S are the sample sizes of the two periods. One-sided tests were performed for the hypotheses. If the difference between the transformed correlations is statistically significant, then it is interpreted as evidence of contagion. The critical value for the z -test at the 5% significance level is 1.645.

The results of z -test for the 1997 Asian crisis are reported in Table II. Panel A shows the test results for both daily returns and two-day returns based on U.S. dollars, while Panel B shows the results for returns based on the local currency. Our z -test results show significant cases of contagion from the Hong Kong market crash, which is similar to the results of other studies. Panel A shows that contagion from Hong Kong occurs to 16 out of 27 countries for daily returns and 11 out of 27 countries for two-day rolling average returns. For the returns based on local currency, Panel B shows that contagion occurs to 15 countries for daily returns and 13 countries for two-day rolling average returns. As mentioned earlier, the constant correlation test is not accurate due to a statistical bias caused by heteroskedasticity.

¹⁰ For example, Kocherlakota and Singh (1982) showed that the Fisher's z -transformation is robust to samples drawn from bivariate t and bivariate χ^2 distributions.

Insert Table 2 about here

4.2.2. Time-Varying Conditional Correlation Test for Contagion

We estimated the dynamic conditional correlation (DCC) model to capture the time-varying nature of the conditional correlation and two modified DCC models to capture a structural break in the conditional correlation dynamics during the crisis period. Table III presents the results of our time-varying conditional correlation test for contagion from the 1997 Asian crisis, with the estimates of the DCC model and the two modified DCC models. We used both daily and two-day rolling average returns based on U.S. dollars from January 1, 1996 to October 16, 1997 as the stable period and from October 17, 1997 to November 14, 1997 as the crisis period.

For estimations, we used the Constrained Maximum Likelihood (CML) module in GAUSS, and report the estimated values with the Bollerslev-Wooldridge heteroscedastic-consistent standard errors. It should be noted that the coefficients of all three DCC models in the CML procedure are restricted to be greater than zero, such that, when restrictions are binding, the standard errors of the coefficients are not reported. For the likelihood ratio tests of financial contagion, the base DCC model is used as a restricted model, while the two modified DCC models are used as unrestricted models. “z-test” in the table refers to the results of the conventional z-test of contagion, and “N” and “C” stand for no contagion and contagion, respectively. Also, “?” refers to the log likelihood ratio test results of contagion. “LL” is the log likelihood value of the estimated DCC models.

Panel A of Table III presents test results of the 1997 Asian crisis for daily returns. For the log likelihood ratio test, Model 1 is used as a null model, while models 2 and 3 are used as an alternative

model. Note that model 2 is to capture a structural break in the autoregressive process of the conditional correlation, while model 3 is to capture a structural break in both the autoregressive process and the news impact process. The test results for model 2 show that none of the countries exhibited contagion evidence, while the results for model 3 show only two countries (the Philippines and Italy) exhibited contagion evidence. This result is completely different from the z-test results, which show that contagion occurred in 16 out of 27 countries during the Asian crisis. Note that the estimated value of δ^c and γ^c is close to zero for the most countries except for Philippines and Italy. This implies that there is no significant jump in the conditional correlation dynamics during the crisis period once the conditional correlation is modeled by the time-varying cross-market volatilities.

Panel B of Table III shows test results of the Asian crisis for two-day rolling average returns. Test results of both models show that, out of 11 countries reported as contagion evidence from the z-test, contagion occurred only to the Philippines. The estimated value of δ^c is positive and statistically significant at the 5% level, implying that there was a sudden jump in the conditional correlation dynamics for the Philippines.

Insert Table 3 about here

We also performed the time-varying conditional correlation test for the returns based on local currencies. Test results are reported in Table IV. Panel A of Table IV shows test results of the Asian crisis for daily returns, and Panel B presents the results for two-day rolling average returns. First, the z-test results show that contagion from Hong Kong occurred to 15 out of 27 countries for daily returns and 11

out of 27 countries for two-day rolling average returns. Second, Panel A shows that, while none of the countries exhibited contagion evidence under model 2, only two countries (the Philippines and Italy) exhibited contagion under model 3. Third, Panel B shows that under two-day rolling average returns only the Philippines exhibited contagion evidence out of 11 countries reported as contagion evidence by the z-test. These results are the same as those for the U.S. dollar-based returns, implying that the results are robust to the different currency-based returns.

Insert Table 4 about here

In summary, our time-varying conditional correlation test shows a completely different result from those of the constant correlation test. Our modified DCC test results show that only the Philippines and Italy (or only the Philippines with two-day rolling average returns) exhibited contagion evidence from the 1997 Asian crisis, while the z-test indicates that contagion from Hong Kong occurred to 16 out of 27 countries (or 11 countries with two-day rolling average returns). This difference between the two tests is mainly due to the failure of the z-test to incorporate the time-varying nature of cross-market co-movements into the correlation test. Statistically significant increases in the constant correlation reported as contagion evidence by the z-test disappear in our time-varying conditional correlation test. This implies that the high correlation during the crisis period is attributed to the high level of cross-market co-movements induced by rational risk-averse investors who systematically adjust their investment positions along with their perceived high future volatility for the crisis country during the crisis period.

5. Test for the 1994 Mexican Peso Crisis and the 1987 U.S. Market Crash

5.1. Test for the 1994 Mexican Peso Crisis

We also performed the contagion tests for the 1994 Mexican peso crisis. We used U.S. dollar-based returns for the period from January 1, 1993 to December 18, 1994 as the stable period and the period from December 19, 1994 to December 31, 1994 as the crisis period. The z-test results for the peso crisis are reported in Table V, which shows that only two countries (Sweden and Brazil) exhibited contagion evidence for daily dollar-based returns and three countries (Spain, Brazil, and Chile) for two-day rolling average returns. During the stable period, most East Asian and European countries, after controlling for domestic and global factors, show a relatively low correlation with Mexico with an average of 0.036 and 0.065, respectively, for daily returns. Countries in both Latin America and North America show a relatively high correlation with Mexico with an average during the stable period of 0.237. During the crisis period, the correlation substantially increases for Sweden and Brazil to 0.793 and 0.754, respectively, leading to contagion in the two countries. The similar situation happens to Spain, Brazil, and Chile when using two-day rolling average returns. Again, since the z-test is not capable of capturing the time-varying nature of cross-market co-movements, its results are not accurate and reliable for the test of contagion.

Insert Table 5 about here

Table VI presents the results of the time-varying conditional correlation test. It shows that none of 26 countries exhibited contagion evidence from the peso crisis for both daily and two-day rolling average

returns. Test results shown in Panels A and B imply that there was no irrational market reaction to the peso crisis to lead to contagion, but only time-varying rational responses to the crisis. Our results are consistent with those results reported by Bakaert, Harvey, and Ng (2005), Rigobon (2003), and Rodriguez (2007), concluding that the 1994 Mexican peso crisis was relatively less severe than other crisis episodes. Therefore, we conclude that there was no contagion from the 1994 Mexican peso crisis to the national stock markets.

Insert Table 6 about here

5.2. Test for the 1987 U.S. Stock Market Crash

For the 1987 U.S. stock market crash, Table VII reports the z-test results for both daily returns and two-day rolling average returns based on U.S. dollars. It shows that for daily returns, contagion from the U.S. market occurred to four out of nine countries, Australia, Japan, the U.K. and Canada, with an average correlation of 0.711 during the crisis period and 0.270 during the stable period. However, for two-day rolling average returns, six out of nine countries exhibited contagion from U.S. market, with an average correlation of 0.560 during the crisis period and 0.116 during the stable period.

Insert Table 7 about here

However, the results of the time-varying conditional correlation test reported in Table VIII show that none of the nine countries exhibited contagion evidence from the 1987 stock market crash. Our results for the 1987 U.S. market crash are similar to those found for the 1994 peso crisis. The results for both the Mexican peso crisis and the U.S. market crash confirm the role of time-varying rationality in the test of contagion. They show that contagion evidence reported by the z-test disappears after controlling the time-varying nature of cross-market co-movements. In sum, our test results for the 1994 peso crisis and the 1987 U.S. market crash confirms that the high correlation during the crisis period is mostly attributed to a high level of cross-market co-movements induced by risk-averse investors rationally responding to the high level of predictable volatility of the crisis country during the crisis period.

Insert Table 8 about here

6. Summary and Conclusion

In this paper, we suggest and demonstrate that there is a significant time-varying relationship between cross-market co-movements and predictable cross-market market volatilities, and that the time-varying component of the cross-market correlation is due to the rational responses by risk-averse investors who systematically revise their expectations in response to their perceived future volatility.

We propose a time-varying conditional correlation test for contagion to correctly reflect the correlation-volatility relation in the test. In this time-varying correlation test, contagion is defined as a structural break in the dynamics of conditional correlation during the crisis period. Using the dynamic

conditional correlation (DCC) model, we found that (a) only the Philippines and Italy show evidence of contagion from the 1997 Asian crisis, and (b) none of the countries considered in the test show contagion evidence from the 1994 Mexican peso crisis and 1987 U.S. stock market crash.

Our results imply that a high correlation during the crisis time period reported as contagion evidence by the constant correlation test is mostly attributable to the high level of cross-market co-movements induced by the rational risk-averse investors during the crisis period. In general, risk-averse investors rationally respond to the crisis by adjusting their investment positions along with their perceived high future volatility for the crisis country during the crisis period.

Appendix

List of Interest Rates

Country	Interest Rate
<i>East Asia</i>	
Hong Kong	Hong Kong Interbank 3 month rate
Australia	Dealer bill 90 days rate
Indonesia	Indonesia interbank call rate.
Japan	Japan interbank 3 month rate
Korea	Certificates of deposits 91 day rate
Malaysia	Offshore 3 month rate
Philippines	Philippines' interbank call loan rate
Singapore	Singapore Interbank 3 month rate
Taiwan	Taiwan money market 90 day rate
Thailand	Thailand interbank 3 month rate
<i>Europe</i>	
Belgium	Belgium interbank offered 3 month rate
France	French Euro-Franc 3 month rate
Germany	Germany Euro-Mark 3 month rate
Italy	Euro-Lira 3 month rate
Netherlands	Netherlands' Interbank 3 month rate
Russia	Moscow interbank offered rate 90-day rate
Spain	Spain interbank 3 month rate
Sweden	Sweden Treasury bill 90 day rate
Swiss	Swiss interbank 3 month rate
U.K.	U.K. Treasury bills 3 month rate
<i>South America</i>	
Argentina	Deposit rate per annum 90 day rate
Brazil	Financing overnight rate
Canada	Euro Currency Canadian Dollar 3 month rate
Chile	CD 90 day rate
Mexico	CETES 91 day closing rate
U.S.	U.S. Treasury bills 3 month rate
<i>Africa</i>	
S. Africa	Bond yield

References

- Ang, Andrew, and Joseph Chen, 2002, Asymmetric correlations of equity portfolios, *Journal of Financial Economics* 63, 443-494.
- Baba, Yoshihisa, Robert F. Engle, Dennis F. Kraft, and Kenneth F. Kroner, 1990, Multivariate simultaneous generalized ARCH, Unpublished paper, Department of Economics, UC San Diego, CA.
- Bae, Kee-Hong, G. Andrew Karolyi, and Rene M. Stulz, 2003, A new approach to measuring financial contagion, *Review of Financial Studies* 16, 717-763.
- Baig, Taimur, and Ilan Goldfajn, 1998, Financial market contagion in the Asian crisis, International Monetary Fund, Washington, D.C.
- Ball, Ray, and S.P. Kothari, 1989, Nonstationary expected returns: Implications for tests of market efficiency and serial correlation in returns, *Journal of Financial Economics* 25, 51-74.
- Bera, Anil K., and Sangwhan Kim, 2002, Testing constancy of correlation and other specifications of the BGARCH model with an application to international equity returns, *Journal of Empirical Finance* 9, 171-195.
- Bartram, Sohnke M., and Yaw-Huei Wang, 2005, Another look at the relationship between cross-market correlation and volatility, *Finance Research Letters* 2, 75-88.
- Bekaert, Geert, Campbell R. Harvey, and Angela Ng, 2005, Market integration and contagion, *Journal of Business* 78, 39-70.
- Bollerslev, Timothy, 1990, Modelling the coherence in short-run nominal exchange rates: A multivariate generalized approach, *Review of Economics and Statistics* 72, 498-505.
- Bollerslev, Timothy, Robert F. Engle, and Jeffrey M. Wooldridge, 1988, A capital asset pricing model with time-varying covariances, *Journal of Political Economy* 96, 116-131.
- Boyer, Brian H., Michael S. Gibson, and Mico Loretan, 1999, Pitfalls in tests for changes in correlations, International Finance Division Discussion Paper No. 597R, Federal Reserve Board, Washington, D.C.
- Boyer, Brian H., Tomomi Kumagai, and Kathy Yuan, 2006, How do crises spread?: Evidence from accessible and inaccessible stock indices, *Journal of Finance* 61, 957-1003.
- Broner, Fernando A., R. Gaston Gelos, and Carmen M. Reinhart, 2006, When in peril, retrench: Testing the portfolio channel of contagion, *Journal of International Economics* 69, 203-230.
- Caporale, Guglielmo M., Andrea Cipollini, and Nicola Spagnolo, 2005, Testing for contagion: A conditional correlation analysis, *Journal of Empirical Finance* 12, 476-489.

- Cecchetti, Stephen G., Pok-Sang Lam, and Nelson C. Mark, 1990, Mean reversion in equilibrium asset prices, *American Economic Review* 80, 398-418.
- Chakrabarti, Rajesh, and Richard Roll, 2002, East Asia and Europe during the 1997 Asian collapse: A clinical study of a financial crisis, *Journal of Financial Markets* 5, 1-30.
- Calvo, Sara, and Carmen M. Reinhart, 1996, Capital flows to Latin America: Is there evidence of contagion effects?, in Guillermo A. Calvo, Morris Goldstein, and Eduard Hochreiter, eds.: *Private Capital Flows to Emerging Markets after the Mexican Crisis* (Institute for International Economics, Washington, D.C.).
- Corsetti, Giancarlo, Marcello Pericoli, and Massimo Sbracia, 2005, 'Some contagion, some interdependence': more pitfalls in tests of financial contagion, *Journal of International Money and Finance* 24, 1177-1199.
- De Bondt, Werner F.M., and Richard Thaler, 1985, Does the stock market overreact?, *Journal of Finance* 40, 793-805.
- De Bondt, Werner F.M., and Richard Thaler, 1987, Further evidence on investor overreaction and stock market seasonality, *Journal of Finance* 42, 557-582.
- Engle, Robert F., 2002, Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroscedasticity models, *Journal of Business and Economic Statistics* 20, 339-350.
- Engle, Robert F., and Kevin Sheppard, 2001, Theoretical and empirical properties of dynamic conditional correlation multivariate GARCH, Working paper, UC San Diego, CA.
- Fama, Eugene F., and Kenneth R. French, 1988, Permanent and temporary components of stock prices, *Journal of Political Economy* 96, 246-273.
- Forbes, Kristine J., and Roberto Rigobon, 2002, No contagion, only interdependence: Measuring stock market co-movements, *Journal of Finance* 57, 2223-2261.
- Gromb, Denis, and Dimitri Vayanos, 2002, Equilibrium and welfare in markets with financially constrained arbitrageurs, *Journal of Financial Economics* 66, 361-407.
- Hays, William L., 1994, *Statistics*, 5th ed. (Wadsworth Publishing Company).
- Karolyi, G. Andrew, and Rene M. Stulz, 1996, Why do markets move together? An investigation of U.S.-Japan stock return comovements, *Journal of Finance* 51, 951-986.
- King, Mervyn A., and Sushil Wadhvani, 1990, Transmission of volatility between stock markets, *Review of Financial Studies* 3, 5-33.

- Kocherlakota, Subrahmaniam, and Murari Singh, 1982, On the behavior of some transforms of the sample correlation coefficient in samples from the bivariate t and the bivariate χ^2 distribution, *Communications in Statistics-Theory and Methods* 11, 2045-2060.
- Kodres, Laura E., and Matthew Pritsker, 2002, A rational expectations model of financial contagion, *Journal of Finance* 57, 769-799.
- Kraft, Dennis F., and Robert F. Engle, 1982, Autoregressive conditional heteroscedasticity in multiple time series, Unpublished paper, Department of Economics, UC San Diego, CA.
- Kyle, Albert S., and Wei Xiong, 2001, Contagion as a wealth effect, *Journal of Finance* 56, 1401-1440.
- Lehmann, Bruce, 1990, Fads, martingales, and market efficiency, *Quarterly Journal of Economics* 105, 1-28.
- Lo, Andrew W., and A. Craig MacKinlay, 1990, When are contrarian profits due to stock market overreaction?, *Review of Financial Studies* 3, 175-208.
- Longin, Francois, and Bruno Solnik, 1995, Is the correlation in international equity returns constant: 1960-1990?, *Journal of International Money and Finance* 14, 3-26.
- Longin, Francois, and Bruno Solnik, 2001, Extreme correlation of international equity markets, *Journal of Finance* 56, 649-676.
- Loretan, Mico, and William B. English, 2000, Evaluating "correlation breakdowns" during periods of market volatility, International Finance Division Discussion Paper No. 658, Federal Reserve Board, Washington, D.C.
- Masson, Paul R., 1999, Contagion: Monsoonal effects, spillovers, and jumps between multiple equilibria, in Pierre-Richard Agenor, Marcus Miller, David Vines, and Axel Weber, eds.: *The Asian Financial Crises: Causes, Contagion and Consequences* (Cambridge University Press, Cambridge, U.K.).
- Mullainathan, Sendhil, 2002, A memory based model of bounded rationality, *Quarterly Journal of Economics* 117, 735-774.
- Park, Yung Chul, and Chi-Young Song, 2001, Financial contagion in the East Asian crisis: With special reference to the Republic of Korea, in Stijn Claessens, and Kristine J. Forbes, eds.: *International Financial Contagion* (Kluwer Academic Publishers, Norwell, MA).
- Poterba, James M., and Lawrence H. Summers, 1988, Mean reversion in stock returns: Evidence and implications, *Journal of Financial Economics* 22, 27-60.
- Ramchand, Latha, and Raul Susmel, 1998, Volatility and cross correlation across major stock markets, *Journal of Empirical Finance* 5, 397-416.

- Rigobon, Roberto, 2003, On the measurement of the international propagation of shocks: Is the transmission stable?, *Journal of International Economics* 61, 261-283.
- Rodriguez, Juan C., 2007, Measuring financial contagion: A copula approach, *Journal of Empirical Finance* 14, 401-423.
- Schiller, Robert J., 1984, Stock prices and social dynamics, *Brookings Papers on Economic Activity* 2, 457-498.
- Summers, Lawrence H., 1986, Does the stock market rationally reflect fundamental values?, *Journal of Finance* 41, 591-600.
- Tse, Yiu Kuen, 2000, A test for constant correlations in a multivariate GARCH model, *Journal of Econometrics* 98, 107-127.
- Valdes, Rodrigo, 1996, Emerging market contagion: Evidence and theory, Working paper, MIT.
- Wongswan, Jon, 2003, Contagion: An empirical test, International Finance Discussion Papers No. 775, Federal Reserve Board, Washington, D.C.
- Yuan, Kathy, 2005, Asymmetric price movements and borrowing constraints: A rational expectations equilibrium model of crises, contagion, and confusion, *Journal of Finance* 60, 379-411.

Table 1

Summary Statistics of Daily and Two-day Rolling Average Returns for the 1997 Asian Crisis

The source of the data is Datastream. Summary statistics include the mean (Mean), standard deviation (SD), skewness (Skew), kurtosis (Kurt), minimum (Min), maximum (Max), and the p-values of the Ljung-Box statistics ($Q(12)$). Both daily and two-day rolling average returns are based on U.S. dollars. Countries in the sample include Australia (AUS), Hong Kong (HK), India (INA), Indonesia (IND), Japan (JAP), Korea (KOR), Malaysia (MAL), the Philippines (PHI), Singapore (SIN), Taiwan (TWN), Thailand (THA), Belgium (BEL), France (FRA), Germany (GER), Italy (ITA), the Netherlands (NET), Russia (RUS), Spain (SPA), Sweden (SWE), Switzerland (SWI), the U.K. (UK), Argentina (ARG), Brazil (BRA), Chile (CHI), Mexico (MEX), Canada (CAN), the U.S. (US), and South Africa (SA). $Q(12)$ is the Ljung-Box statistic for the 12th order serial correlation of *squared* returns.

Country	Panel A: Daily Returns							Panel B: Two-day Moving Average Returns						
	Mean	SD	Skew	Kurt	Min	Max	$Q(12)$	Mean	SD	Skew	Kurt	Min	Max	$Q(12)$
<i>Asia</i>														
AUS	0.01	0.98	-0.31	10.07	-5.63	6.41	0.00	0.01	0.69	-1.11	10.74	-5.09	2.68	0.00
HK	-0.00	1.79	-0.20	25.26	-13.58	15.56	0.00	-0.01	1.20	-2.02	19.71	-9.41	6.36	0.00
INA	0.05	1.33	0.40	9.23	-7.08	8.71	0.98	0.05	1.04	0.43	6.14	-3.69	5.49	0.00
IND	-0.11	2.10	0.12	16.43	-13.67	14.47	0.00	-0.11	1.64	0.13	10.96	-7.05	9.48	0.00
JAP	-0.09	1.05	-0.04	4.34	-3.88	3.79	0.00	-0.09	0.75	-0.27	4.34	-3.41	2.09	0.00
KOR	-0.17	1.72	-0.33	8.20	-8.92	7.77	0.00	-0.17	1.36	-0.53	10.20	-8.64	7.55	0.00
MAL	-0.13	1.67	0.89	21.29	-10.39	13.80	0.00	-0.13	1.31	1.14	18.10	-6.47	10.65	0.00
PHI	-0.11	1.54	-0.54	8.92	-9.71	6.75	0.00	-0.12	1.22	-0.54	7.50	-6.52	5.62	0.00
SIN	-0.08	1.09	-0.04	12.01	-6.65	7.70	0.00	-0.08	0.80	0.18	8.54	-3.48	4.86	0.00
TWN	0.07	1.69	-0.96	10.39	-12.30	5.80	0.00	0.08	1.20	-0.85	9.49	-8.33	5.37	0.00
THA	-0.28	2.38	0.25	8.08	-9.72	14.01	0.00	-0.29	1.81	0.48	6.52	-8.09	7.99	0.00
<i>Europe</i>														
BEL	0.04	0.68	-0.36	4.60	-2.74	2.39	0.00	0.04	0.51	-0.33	4.55	-2.28	1.62	0.00
FRA	0.04	0.85	-0.04	6.74	-3.79	5.14	0.00	0.04	0.60	-0.35	4.01	-2.08	1.88	0.00
GER	0.04	0.89	-0.67	7.18	-5.19	4.26	0.00	0.04	0.59	-0.85	7.65	-3.88	2.07	0.00
ITA	0.07	1.23	0.26	5.92	-5.09	5.93	0.00	0.07	0.89	0.24	4.89	-3.53	3.65	0.00
NET	0.07	0.90	-0.15	5.06	-4.00	4.30	0.00	0.07	0.62	-0.33	4.07	-2.09	2.10	0.00
RUS	0.33	2.94	-0.01	15.44	-19.66	20.08	0.00	0.33	2.09	-0.38	9.85	-14.3	8.94	0.00
SPA	0.07	0.96	-0.48	7.10	-5.76	4.89	0.00	0.07	0.72	-0.61	6.44	-3.72	3.34	0.00
SWE	0.09	1.01	-0.13	7.25	-5.20	6.05	0.00	0.09	0.73	-0.54	5.70	-3.97	2.32	0.00
SWI	0.05	0.85	-0.25	4.05	-3.08	2.57	0.00	0.05	0.63	0.02	3.14	-1.72	1.78	0.00
UK	0.06	0.68	-0.04	4.75	-3.10	3.47	0.31	0.07	0.50	-0.25	4.02	-2.14	1.71	0.00
<i>Latin America</i>														
ARG	0.03	1.53	-1.89	16.69	-13.44	5.65	0.00	0.03	1.14	-1.47	10.93	-8.59	3.51	0.00
BRA	0.02	1.49	-2.18	17.08	-10.75	5.53	0.00	0.02	1.11	-1.80	10.74	-5.89	4.03	0.00
CHI	-0.02	0.77	-0.24	7.69	-5.27	2.89	0.00	-0.02	0.61	-0.18	5.29	-3.10	1.96	0.00
MEX	0.06	1.40	-1.97	22.23	-13.49	5.69	0.00	0.06	1.07	-1.43	13.18	-8.44	3.75	0.00
<i>North America</i>														
CAN	0.08	0.73	-1.79	17.92	-6.62	2.33	0.05	0.08	0.56	-0.97	7.85	-3.59	1.70	0.00
US	0.09	0.90	-0.87	10.81	-6.80	4.31	0.00	0.09	0.65	-0.40	5.57	-3.83	2.13	0.00
<i>Africa</i>														
SA	-0.03	1.33	-2.52	36.70	-14.48	8.18	0.00	-0.03	0.93	-3.17	40.37	-10.8	4.52	0.00

Table 2

The z-test results for 1997 Asian crisis

This table presents the z-test results of contagion for the 1997 Asian crisis. We specify the univariate GARCH (1,1) process to capture the heteroscedasticity of returns. The stable period is from January 1, 1996 to October 16, 1997, while the crisis period is from October 17, 1997 to November 14, 1997. The full period includes both the stable and turmoil periods. The test statistics are for one-sided tests examining if the correlation coefficient during the turmoil period is greater than during the stable period. The p-values of the test statistics are reported in parentheses. “C” means a contagion with the test statistic significant at the 5% level, while “N” indicates that the test statistic is insignificant at the 5% level and therefore no contagion occurred.

Panel A. Results for returns based on U.S. dollar										
Country	Daily Returns					Two-day Moving Average Returns				
	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?
<i>Asia</i>										
Australia	0.359	0.729	0.497	2.29	C	0.336	0.611	0.427	1.50	N
India	0.031	-0.115	0.013	-0.61	N	0.073	0.039	0.062	-0.14	N
Indonesia	0.247	0.737	0.430	2.88	C	0.207	0.587	0.341	1.92	C
Japan	0.263	0.371	0.258	0.50	N	0.245	0.300	0.239	0.25	N
Korea	0.081	0.277	0.159	0.84	N	0.094	0.016	0.071	-0.33	N
Malaysia	0.223	0.715	0.373	2.79	C	0.196	0.574	0.315	1.89	C
Philippines	0.181	0.732	0.328	3.12	C	0.192	0.779	0.339	3.53	C
Singapore	0.327	0.799	0.493	3.15	C	0.322	0.731	0.448	2.48	C
Taiwan	0.120	0.128	0.122	0.03	N	0.123	-0.053	0.065	-0.73	N
Thailand	0.059	0.087	0.066	0.12	N	0.026	0.232	0.083	0.87	N
<i>Europe</i>										
Belgium	0.111	0.387	0.165	1.24	N	0.118	0.295	0.149	0.77	N
France	0.138	0.690	0.288	2.95	C	0.114	0.592	0.247	2.35	C
Germany	0.297	0.696	0.421	2.30	C	0.298	0.558	0.375	1.34	N
Italy	0.105	0.722	0.232	3.35	C	0.067	0.640	0.190	2.87	C
Netherlands	0.233	0.692	0.333	2.55	C	0.237	0.545	0.303	1.53	N
Russia	0.103	0.726	0.330	3.39	C	0.117	0.644	0.308	2.69	C
Spain	0.101	0.551	0.225	2.16	C	0.084	0.418	0.171	1.50	N
Sweden	0.134	0.654	0.297	2.69	C	0.091	0.531	0.229	2.08	C
Switzerland	0.134	0.589	0.214	2.25	C	0.143	0.537	0.216	1.90	C
U.K.	0.133	0.643	0.248	2.62	C	0.116	0.528	0.201	1.96	C
<i>Latin America</i>										
Argentina	0.089	-0.112	0.008	-0.84	N	0.125	-0.239	-0.017	-1.53	N
Brazil	0.114	0.158	0.138	0.19	N	0.129	-0.062	0.063	-0.80	N
Chile	0.043	0.432	0.164	1.75	C	0.042	0.204	0.088	0.68	N
Mexico	0.173	0.296	0.230	0.54	N	0.213	0.098	0.173	-0.49	N
<i>North America</i>										
Canada	0.111	0.234	0.159	0.53	N	0.104	-0.087	0.040	-0.80	N
U.S.	0.060	-0.048	0.022	-0.45	N	0.095	-0.235	-0.012	-1.40	N
<i>Africa</i>										
S. Africa	0.246	0.745	0.499	2.96	C	0.241	0.665	0.439	2.31	C

Panel B. Results for returns based on local currency										
Country	Daily Returns					Two-day Moving Average Returns				
	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?
<i>Asia</i>										
Australia	0.403	0.630	0.490	1.31	N	0.370	0.534	0.429	0.86	N
India	0.042	-0.120	0.020	-0.68	N	0.080	0.062	0.069	-0.07	N
Indonesia	0.291	0.643	0.383	1.93	C	0.304	0.586	0.390	1.48	N
Japan	0.280	0.511	0.312	1.15	N	0.277	0.433	0.299	0.75	N
Korea	0.083	0.269	0.155	0.80	N	0.100	-0.014	0.064	-0.47	N
Malaysia	0.293	0.783	0.411	3.13	C	0.247	0.655	0.355	2.21	C
Philippines	0.288	0.787	0.404	3.19	C	0.298	0.814	0.415	3.45	C
Singapore	0.352	0.820	0.508	3.28	C	0.344	0.784	0.473	2.90	C
Taiwan	0.124	0.135	0.122	0.05	N	0.130	-0.049	0.075	-0.75	N
Thailand	0.086	0.126	0.089	0.17	N	0.055	0.281	0.103	0.97	N
<i>Europe</i>										
Belgium	0.162	0.656	0.302	2.59	C	0.179	0.541	0.265	1.77	C
France	0.163	0.754	0.351	3.40	C	0.145	0.649	0.300	2.61	C
Germany	0.317	0.742	0.471	2.60	C	0.329	0.611	0.420	1.53	N
Italy	0.112	0.747	0.272	3.56	C	0.080	0.661	0.222	2.97	C
Netherlands	0.239	0.749	0.374	3.03	C	0.248	0.618	0.338	1.95	C
Russia	0.140	0.743	0.382	3.40	C	0.166	0.673	0.357	2.70	C
Spain	0.133	0.663	0.301	2.77	C	0.125	0.504	0.235	1.79	C
Sweden	0.138	0.675	0.334	2.83	C	0.108	0.541	0.257	2.07	C
Switzerland	0.176	0.771	0.343	3.52	C	0.202	0.661	0.326	2.45	C
U.K.	0.175	0.787	0.347	3.69	C	0.160	0.682	0.289	2.79	C
<i>Latin America</i>										
Argentina	0.089	-0.112	0.007	-0.84	N	0.124	-0.240	-0.018	-1.54	N
Brazil	0.111	0.155	0.135	0.19	N	0.126	-0.067	0.059	-0.81	N
Chile	0.055	0.267	0.104	0.91	N	0.060	0.024	0.051	-0.15	N
Mexico	0.152	-0.062	0.064	-0.89	N	0.196	-0.246	0.029	-1.87	N
<i>North America</i>										
Canada	0.109	0.141	0.122	0.13	N	0.112	-0.121	0.030	-0.97	N
U.S.	0.060	-0.047	0.022	-0.44	N	0.096	-0.234	-0.011	-1.39	N
<i>Africa</i>										
S. Africa	0.299	0.733	0.536	2.60	C	0.302	0.648	0.476	1.91	C

Table 3

Time-Varying Conditional Correlation Test of the 1997 Asian Crisis for Returns Based on U.S. Dollars

The likelihood ratio (LR) tests of financial contagion are based on the Engle (2002)'s dynamic conditional correlation (DCC) model as a restricted model and the two modified DCC models as unrestricted models. The models are specified as:

Model 1(DCC model): $Q_t = (1-\delta-\gamma)\bar{Q} + \delta Q_{t-1} + \gamma v_{t-1}'v_{t-1}$

Model 2 (Modified DCC model A): $Q_t = (1-\delta-D\delta^C-\gamma)\bar{Q} + (\delta+D\delta^C)Q_{t-1} + \gamma v_{t-1}'v_{t-1}$

Model 3 (Modified DCC model B): $Q_t = (1-\delta-D\delta^C-\gamma-D\gamma^C)\bar{Q} + (\delta+D\delta^C)Q_{t-1} + (\gamma+D\gamma^C)v_{t-1}'v_{t-1}$,

where \bar{Q} is the unconditional covariance matrix of the standardized residual vector v_t , and D is a dummy variable taking value 1 for the crisis period and 0 for the stable period. The stable period is from January 1, 1996 to October 16, 1997 and the crisis period is from October 17, 1997 to November 14, 1997. The test hypotheses for the model 1 and model 2 are $H_0 : \delta^C = 0$ and $H_0 : \delta^C = \gamma^C = 0$, respectively. “z-test” refers to the results of conventional z-test of contagion, and “N” stands for no contagion and “C” for contagion. “?” refers to the LR test results of contagion. “LL” is the log likelihood value of the estimated DCC models. We use the Constrained Maximum Likelihood (CML) module in GAUSS. The Bollerslev-Wooldridge heteroscedastic-consistent standard errors are reported in parentheses.

Panel A: Results for daily returns based on U.S. dollars															
z-test		Model 1: DCC Model			Model 2: Modified DCC Model A					Model 3: Modified DCC Model B					
		δ	γ	LL	δ	δ^C	γ	LL	?	δ	δ^C	γ	γ^C	LL	?
<i>Asia</i>															
AUS	C	0.736 (0.086)	0.103 (0.051)	-1357.83	0.736 (0.086)	0.000 (0.000)	0.103 (0.051)	-1357.83	N	0.736 (0.086)	0.000 (0.000)	0.103 (0.051)	0.000 (0.000)	-1357.83	N
INA	N	0.910 (0.079)	0.001 (0.020)	-1570.52	0.910 (0.080)	0.000 (0.000)	0.000 (0.020)	-1570.52	N	0.910 (0.076)	0.000 (0.000)	0.000 (0.020)	0.000 (0.000)	-1570.52	N
IND	C	0.892 (0.061)	0.051 (0.026)	-1592.87	0.892 (0.061)	0.000 (0.000)	0.051 (0.026)	-1592.87	N	0.866 (0.075)	0.000 (0.000)	0.049 (0.024)	0.085 (0.070)	-1591.72	N
JAP	N	0.825 (0.064)	0.019 (0.022)	-1424.90	0.825 (0.064)	0.000 (0.000)	0.019 (0.022)	-1424.90	N	0.825 (0.064)	0.000 (0.000)	0.019 (0.022)	0.000 (0.000)	-1424.90	N
KOR	N	0.234 (0.352)	0.059 (0.063)	-1635.42	0.234 (0.352)	0.000 (0.000)	0.059 (0.063)	-1635.42	N	0.233 (0.353)	0.000 (0.000)	0.059 (0.063)	0.000 (0.000)	-1635.42	N
MAL	C	0.986 (0.022)	0.004 (0.008)	-1444.54	0.986 (0.023)	0.000 (0.000)	0.004 (0.009)	-1444.54	N	0.931 (0.038)	0.000 (0.000)	0.000 (0.000)	0.069 (0.038)	-1443.42	N
PHI	C	0.878 (0.065)	0.013 (0.025)	-1505.47	0.878 (0.065)	0.000 (0.000)	0.013 (0.025)	-1505.47	N	0.822 (0.140)	0.000 (0.000)	0.000 (0.000)	0.129 (0.074)	-1502.28	C
SIN	C	0.889 (0.058)	0.037 (0.018)	-1403.37	0.889 (0.058)	0.000 (0.000)	0.037 (0.018)	-1403.37	N	0.907 (0.048)	0.000 (0.000)	0.027 (0.017)	0.039 (0.034)	-1402.66	N
TWN	N	0.946 (0.033)	0.000 (0.000)	-1644.50	0.935 (0.054)	0.010 (0.040)	0.000 (0.000)	-1644.50	N	0.930 (0.063)	0.009 (0.055)	0.000 (0.000)	0.000 (0.000)	-1644.50	N
THA	N	0.984 (0.007)	0.012 (0.009)	-1764.06	0.984 (0.007)	0.000 (0.000)	0.012 (0.009)	-1764.06	N	0.984 (0.007)	0.000 (0.000)	0.012 (0.009)	0.000 (0.000)	-1764.06	N

<i>Europe</i>															
BEL	N	0.964 (0.020)	0.004 (0.010)	-1245.38	0.964 (0.020)	0.000 (0.000)	0.004 (0.010)	-1245.38	N	0.964 (0.020)	0.000 (0.000)	0.004 (0.010)	0.000 (0.000)	-1245.38	N
FRA	C	0.911 (0.072)	0.017 (0.015)	-1337.61	0.904 (0.069)	0.077 (0.065)	0.018 (0.014)	-1337.54	N	0.778 (0.083)	0.000 (0.000)	0.000 (0.000)	0.202 (0.093)	-1335.73	N
GER	C	0.813 (0.074)	0.087 (0.038)	-1305.47	0.813 (0.074)	0.000 (0.000)	0.087 (0.038)	-1305.47	N	0.788 (0.113)	0.000 (0.000)	0.089 (0.039)	0.117 (0.113)	-1304.86	N
ITA	C	0.529 (0.349)	0.094 (0.058)	-1529.35	0.000 (0.000)	0.785 (0.085)	0.178 (0.070)	-1528.28	N	0.000 (0.000)	0.534 (0.103)	0.089 (0.072)	0.340 (0.124)	-1525.72	C
NET	C	0.938 (0.035)	0.018 (0.018)	-1340.90	0.933 (0.036)	0.048 (0.034)	0.018 (0.017)	-1340.83	N	0.644 (0.132)	0.000 (0.000)	0.000 (0.000)	0.346 (0.148)	-1338.02	N
RUS	C	0.000 (0.000)	0.158 (0.073)	-1865.74	0.000 (0.000)	0.472 (0.298)	0.170 (0.078)	-1864.20	N	0.000 (0.000)	0.472 (0.298)	0.170 (0.078)	0.000 (0.000)	-1864.20	N
SPA	C	0.000 (0.000)	0.159 (0.063)	-1401.60	0.000 (0.000)	0.000 (0.000)	0.159 (0.063)	-1401.60	N	0.000 (0.000)	0.000 (0.000)	0.156 (0.081)	0.008 (0.144)	-1401.60	N
SWE	C	0.920 (0.058)	0.026 (0.019)	-1429.73	0.921 (0.063)	0.008 (0.410)	0.026 (0.023)	-1429.73	N	0.655 (0.086)	0.000 (0.000)	0.035 (0.054)	0.310 (0.107)	-1428.12	N
SWI	C	0.000 (0.000)	0.094 (0.073)	-1352.41	0.000 (0.000)	0.444 (0.381)	0.091 (0.070)	-1352.27	N	0.000 (0.000)	0.000 (0.000)	0.030 (0.082)	0.540 (0.214)	-1349.47	N
UK	C	0.926 (0.029)	0.038 (0.015)	-1255.12	0.918 (0.038)	0.042 (0.031)	0.040 (0.016)	-1254.95	N	0.923 (0.029)	0.000 (0.000)	0.033 (0.016)	0.044 (0.028)	-1254.44	N
<i>Latin America</i>															
ARG	N	0.334 (0.148)	0.183 (0.093)	-1581.18	0.235 (0.269)	0.134 (0.316)	0.218 (0.108)	-1581.03	N	0.235 (0.269)	0.134 (0.316)	0.218 (0.107)	0.000 (0.000)	-1581.03	N
BRA	N	0.935 (0.062)	0.019 (0.015)	-1515.43	0.929 (0.063)	0.050 (0.054)	0.021 (0.016)	-1514.81	N	0.929 (0.063)	0.050 (0.054)	0.021 (0.016)	0.000 (0.000)	-1514.81	N
CHI	C	0.145 (0.438)	0.087 (0.092)	-1297.14	0.000 (0.000)	0.854 (0.113)	0.146 (0.113)	-1295.89	N	0.000 (0.000)	0.854 (0.113)	0.146 (0.113)	0.000 (0.000)	-1295.89	N
MEX	N	0.909 (0.148)	0.000 (0.000)	-1535.42	0.915 (0.113)	0.016 (0.044)	0.000 (0.000)	-1535.42	N	0.915 (0.107)	0.016 (0.071)	0.000 (0.000)	0.000 (0.000)	-1535.42	N
<i>North America</i>															
CAN	N	0.974 (0.014)	0.000 (0.000)	-1256.12	0.974 (0.014)	0.020 (0.035)	0.000 (0.000)	-1256.12	N	0.974 (0.014)	0.020 (0.083)	0.000 (0.000)	0.000 (0.000)	-1256.12	N
US	N	0.912 (0.034)	0.000 (0.000)	-1382.21	0.896 (0.060)	0.028 (0.078)	0.000 (0.000)	-1382.21	N	0.895 (0.053)	0.027 (0.098)	0.000 (0.000)	0.000 (0.000)	-1382.21	N
<i>Africa</i>															
SA	C	0.546 (1.947)	0.074 (0.220)	-1410.87	0.554 (1.473)	0.000 (0.000)	0.074 (0.169)	-1410.87	N	0.548 (1.854)	0.000 (0.000)	0.074 (0.210)	0.000 (0.000)	-1410.87	N

Panel B: Results for two-day average returns based on U.S. dollars

	z-test	Model 1: DCC Model			Model 2: Modified DCC Model A				?	Model 3: Modified DCC Model B					
		δ	γ	LL	δ	δ^c	γ	LL		δ	δ^c	γ	γ^c	LL	?
<i>Asia</i>															
AUS	N	0.774 (0.187)	0.056 (0.053)	-752.73	0.774 (0.187)	0.000 (0.000)	0.056 (0.053)	-752.73	N	0.774 (0.187)	0.000 (0.000)	0.056 (0.053)	0.000 (0.000)	-752.73	N
INA	N	0.927 (0.044)	0.008 (0.018)	-935.99	0.927 (0.044)	0.000 (0.000)	0.008 (0.018)	-935.99	N	0.927 (0.044)	0.000 (0.000)	0.008 (0.018)	0.000 (0.000)	-935.99	N
IND	C	0.918 (0.057)	0.038 (0.024)	-981.56	0.918 (0.057)	0.000 (0.000)	0.038 (0.024)	-981.56	N	0.924 (0.043)	0.000 (0.000)	0.032 (0.021)	0.043 (0.034)	-981.08	N
JAP	N	0.808 (0.151)	0.013 (0.023)	-806.41	0.808 (0.151)	0.000 (0.000)	0.013 (0.023)	-806.41	N	0.808 (0.150)	0.000 (0.000)	0.013 (0.023)	0.000 (0.000)	-806.41	N
KOR	N	0.964 (0.014)	0.000 (0.000)	-1015.53	0.960 (0.017)	0.020 (0.087)	0.000 (0.000)	-1015.53	N	0.964 (0.014)	0.020 (0.200)	0.000 (0.000)	0.000 (0.000)	-1015.53	N
MAL	C	0.990 (0.031)	0.000 (0.000)	-835.24	0.991 (0.022)	0.000 (0.000)	0.000 (0.000)	-835.24	N	0.990 (0.019)	0.000 (0.000)	0.000 (0.000)	0.010 (0.019)	-835.13	N
PHI	C	0.896 (0.049)	0.028 (0.028)	-885.63	0.000 (0.000)	0.860 (0.049)	0.140 (0.049)	-879.32	C	0.000 (0.000)	0.792 (0.283)	0.082 (0.071)	0.124 (0.222)	-878.60	C
SIN	C	0.914 (0.038)	0.025 (0.017)	-791.33	0.914 (0.038)	0.000 (0.000)	0.025 (0.017)	-791.33	N	0.922 (0.037)	0.000 (0.000)	0.019 (0.018)	0.022 (0.032)	-791.00	N
TWN	N	0.945 (0.026)	0.000 (0.000)	-1013.46	0.945 (0.027)	0.000 (0.000)	0.000 (0.000)	-1013.46	N	0.945 (0.026)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1013.46	N
THA	N	0.983 (0.012)	0.009 (0.009)	-1139.46	0.983 (0.012)	0.000 (0.000)	0.009 (0.009)	-1139.46	N	0.983 (0.012)	0.000 (0.000)	0.009 (0.009)	0.000 (0.000)	-1139.46	N
<i>Europe</i>															
BEL	N	0.975 (0.026)	0.000 (0.000)	-627.39	0.982 (0.012)	0.000 (0.000)	0.000 (0.000)	-627.39	N	0.983 (0.013)	0.002 (0.032)	0.000 (0.000)	0.000 (0.000)	-627.39	N
FRA	C	0.944 (0.031)	0.007 (0.013)	-722.71	0.936 (0.034)	0.056 (0.034)	0.008 (0.012)	-722.66	N	0.797 (0.173)	0.000 (0.000)	0.000 (0.000)	0.061 (0.053)	-722.28	N
GER	N	0.825 (0.092)	0.078 (0.037)	-695.82	0.825 (0.092)	0.000 (0.000)	0.078 (0.038)	-695.82	N	0.825 (0.092)	0.000 (0.000)	0.078 (0.037)	0.000 (0.000)	-695.82	N
ITA	C	0.778 (0.121)	0.059 (0.026)	-900.76	0.777 (0.131)	0.050 (0.172)	0.059 (0.028)	-900.75	N	0.730 (0.104)	0.000 (0.000)	0.057 (0.026)	0.210 (0.119)	-899.51	N
NET	N	0.916 (0.035)	0.032 (0.019)	-723.15	0.914 (0.036)	0.054 (0.031)	0.032 (0.019)	-723.05	N	0.911 (0.040)	0.000 (0.000)	0.032 (0.019)	0.057 (0.035)	-722.93	N
RUS	C	0.763 (0.577)	0.024 (0.066)	-1237.89	0.749 (0.219)	0.224 (0.204)	0.027 (0.036)	-1237.57	N	0.743 (0.243)	0.230 (0.229)	0.027 (0.037)	0.000 (0.000)	-1237.57	N
SPA	N	0.902 (0.091)	0.020 (0.024)	-788.06	0.895 (0.078)	0.084 (0.071)	0.021 (0.021)	-787.95	N	0.894 (0.082)	0.085 (0.076)	0.021 (0.022)	0.000 (0.000)	-787.95	N
SWE	C	0.917 (0.093)	0.024 (0.030)	-803.60	0.917 (0.080)	0.060 (0.064)	0.023 (0.026)	-803.56	N	0.917 (0.080)	0.060 (0.064)	0.023 (0.026)	0.000 (0.000)	-803.56	N
SWI	C	0.985 (0.012)	0.000 (0.000)	-730.64	0.985 (0.013)	0.001 (0.033)	0.000 (0.000)	-730.64	N	0.485 (0.228)	0.000 (0.000)	0.000 (0.000)	0.157 (0.077)	-729.23	N

UK	C	0.917 (0.026)	0.034 (0.016)	-640.45	0.911 (0.030)	0.054 (0.027)	0.034 (0.016)	-640.27	N	0.915 (0.029)	0.000 (0.000)	0.030 (0.016)	0.054 (0.027)	-640.06	N
<i>Latin America</i>															
ARG	N	0.832 (0.134)	0.069 (0.040)	-957.30	0.832 (0.134)	0.000 (0.000)	0.069 (0.040)	-957.30	N	0.832 (0.134)	0.000 (0.000)	0.069 (0.039)	0.000 (0.000)	-957.30	N
BRA	N	0.946 (0.062)	0.016 (0.015)	-900.03	0.946 (0.062)	0.000 (0.000)	0.016 (0.015)	-900.03	N	0.946 (0.062)	0.000 (0.000)	0.016 (0.015)	0.000 (0.000)	-900.03	N
CHI	N	0.000 (0.000)	0.121 (0.067)	-681.78	0.000 (0.000)	0.000 (0.000)	0.121 (0.067)	-681.78	N	0.000 (0.000)	0.000 (0.000)	0.121 (0.067)	0.000 (0.000)	-681.78	N
MEX	N	0.906 (0.030)	0.013 (0.020)	-918.87	0.906 (0.030)	0.000 (0.000)	0.013 (0.020)	-918.87	N	0.906 (0.030)	0.000 (0.000)	0.013 (0.020)	0.000 (0.000)	-918.87	N
<i>North America</i>															
CAN	N	0.818 (0.055)	0.028 (0.040)	-630.77	0.818 (0.055)	0.000 (0.000)	0.028 (0.039)	-630.77	N	0.845 (0.048)	0.000 (0.000)	0.025 (0.034)	0.047 (0.036)	-630.54	N
US	N	0.848 (0.057)	0.025 (0.024)	-755.72	0.848 (0.057)	0.000 (0.000)	0.025 (0.024)	-755.72	N	0.841 (0.095)	0.000 (0.000)	0.015 (0.029)	0.034 (0.050)	-755.46	N
<i>Africa</i>															
SA	C	0.617 (0.416)	0.100 (0.082)	-812.82	0.615 (0.433)	0.000 (0.000)	0.100 (0.084)	-812.81	N	0.617 (0.418)	0.000 (0.000)	0.100 (0.082)	0.000 (0.000)	-812.81	N

Table 4

Time-Varying Conditional Correlation Test of the 1997 Asian Crisis for Returns Based on Local Currencies

The likelihood ratio (LR) tests of financial contagion are based on the Engle (2002)'s dynamic conditional correlation (DCC) model as a restricted model and the two modified DCC models as unrestricted models. The models are specified as:

Model 1(DCC model): $Q_t = (1-\delta-\gamma)\bar{Q} + \delta Q_{t-1} + \gamma v_{t-1}'v_{t-1}$

Model 2 (Modified DCC model A): $Q_t = (1-\delta-D\delta^C-\gamma)\bar{Q} + (\delta+D\delta^C)Q_{t-1} + \gamma v_{t-1}'v_{t-1}$

Model 3 (Modified DCC model B): $Q_t = (1-\delta-D\delta^C-\gamma-D\gamma^C)\bar{Q} + (\delta+D\delta^C)Q_{t-1} + (\gamma+D\gamma^C)v_{t-1}'v_{t-1}$,

where \bar{Q} is the unconditional covariance matrix of the standardized residual vector v_t , and D is a dummy variable taking value 1 for the crisis period and 0 for the stable period. The stable period is from January 1, 1996 to October 16, 1997 and the crisis period is from October 17, 1997 to November 14, 1997. The test hypotheses for the model 1 and model 2 are $H_0 : \delta^C = 0$ and $H_0 : \delta^C = \gamma^C = 0$, respectively. “z-test” refers to the results of conventional z-test of contagion, and “N” stands for no contagion and “C” for contagion. “?” refers to the LR test results of contagion. “LL” is the log likelihood value of the estimated DCC models. We use the Constrained Maximum Likelihood (CML) module in GAUSS. The Bollerslev-Wooldridge heteroscedastic-consistent standard errors are reported in parentheses.

Panel A: Results for daily returns based on local currencies															
z-test	Model 1: DCC Model				Model 2: Modified DCC Model A				?	Model 3: Modified DCC Model B					
	δ	γ	LL	δ	δ^C	γ	LL	δ		δ^C	γ	γ^C	LL	?	
<i>Asia</i>															
AUS	N	0.634 (0.124)	0.127 (0.056)	-1286.48	0.634 (0.124)	0.000 (0.000)	0.127 (0.056)	-1286.48	N	0.634 (0.124)	0.000 (0.000)	0.127 (0.056)	0.000 (0.000)	-1286.48	N
INA	N	0.920 (0.069)	0.003 (0.018)	-1563.88	0.920 (0.069)	0.000 (0.000)	0.003 (0.018)	-1563.88	N	0.920 (0.069)	0.000 (0.000)	0.003 (0.018)	0.000 (0.000)	-1563.88	N
IND	C	0.935 (0.031)	0.029 (0.016)	-1528.47	0.935 (0.031)	0.000 (0.000)	0.029 (0.016)	-1528.47	N	0.937 (0.029)	0.000 (0.000)	0.028 (0.015)	0.033 (0.094)	-1528.32	N
JAP	N	0.835 (0.085)	0.021 (0.031)	-1361.65	0.835 (0.089)	0.000 (0.000)	0.021 (0.031)	-1361.65	N	0.835 (0.095)	0.000 (0.000)	0.021 (0.031)	0.000 (0.000)	-1361.65	N
KOR	N	0.950 (0.023)	0.000 (0.000)	-1617.84	0.952 (0.022)	0.008 (0.075)	0.000 (0.000)	-1617.84	N	0.946 (0.027)	0.007 (0.107)	0.000 (0.000)	0.000 (0.000)	-1617.84	N
MAL	C	0.949 (0.049)	0.019 (0.016)	-1401.91	0.749 (0.535)	0.222 (0.529)	0.030 (0.019)	-1401.75	N	0.930 (0.045)	0.000 (0.000)	0.008 (0.019)	0.062 (0.055)	-1400.76	N
PHI	C	0.888 (0.042)	0.041 (0.023)	-1474.10	0.834 (0.173)	0.121 (0.167)	0.045 (0.024)	-1473.51	N	0.610 (0.309)	0.001 (0.056)	0.000 (0.000)	0.270 (0.201)	-1470.90	C
SIN	C	0.888 (0.054)	0.043 (0.020)	-1384.59	0.886 (0.059)	0.038 (0.119)	0.043 (0.020)	-1384.57	N	0.890 (0.056)	0.000 (0.000)	0.035 (0.020)	0.045 (0.042)	-1383.97	N
TWN	N	0.848 (0.221)	0.000 (0.000)	-1627.80	0.849 (0.254)	0.002 (0.076)	0.000 (0.000)	-1627.79	N	0.849 (0.369)	0.001 (0.065)	0.000 (0.000)	0.000 (0.000)	-1627.79	N
THA	N	0.985 (0.007)	0.011 (0.008)	-1727.16	0.985 (0.007)	0.000 (0.000)	0.011 (0.008)	-1727.16	N	0.985 (0.007)	0.000 (0.000)	0.011 (0.008)	0.000 (0.000)	-1727.16	N
<i>Europe</i>															

BEL	C	0.947 (0.023)	0.028 (0.013)	-1219.50	0.944 (0.028)	0.027 (0.024)	0.029 (0.013)	-1219.43	N	0.939 (0.033)	0.000 (0.000)	0.029 (0.013)	0.032 (0.031)	-1219.18	N
FRA	C	0.932 (0.041)	0.023 (0.015)	-1367.95	0.917 (0.050)	0.058 (0.047)	0.025 (0.015)	-1367.78	N	0.865 (0.364)	0.000 (0.000)	0.015 (0.041)	0.120 (0.401)	-1366.54	N
GER	C	0.830 (0.067)	0.096 (0.040)	-1321.64	0.830 (0.067)	0.000 (0.000)	0.096 (0.040)	-1321.64	N	0.830 (0.066)	0.000 (0.000)	0.096 (0.038)	0.000 (0.162)	-1321.64	N
ITA	C	0.645 (0.221)	0.064 (0.046)	-1517.10	0.549 (0.407)	0.336 (0.384)	0.084 (0.074)	-1516.73	N	0.638 (0.121)	0.000 (0.000)	0.035 (0.041)	0.326 (0.128)	-1512.87	C
NET	C	0.953 (0.034)	0.022 (0.016)	-1373.14	0.947 (0.044)	0.029 (0.038)	0.023 (0.016)	-1373.09	N	0.722 (0.110)	0.000 (0.000)	0.000 (0.000)	0.278 (0.110)	-1371.66	N
RUS	C	0.781 (0.206)	0.092 (0.057)	-1859.28	0.000 (0.000)	0.749 (0.106)	0.181 (0.065)	-1858.53	N	0.000 (0.000)	0.749 (0.106)	0.181 (0.065)	0.000 (0.000)	-1858.53	N
SPA	C	0.640 (0.143)	0.096 (0.049)	-1397.90	0.657 (0.146)	0.255 (0.125)	0.088 (0.057)	-1397.63	N	0.691 (0.093)	0.032 (0.225)	0.082 (0.043)	0.195 (0.217)	-1396.82	N
SWE	C	0.924 (0.056)	0.020 (0.019)	-1404.70	0.911 (0.101)	0.068 (0.093)	0.021 (0.020)	-1404.62	N	0.711 (0.130)	0.000 (0.000)	0.010 (0.059)	0.278 (0.173)	-1403.98	N
SWI	C	0.959 (0.040)	0.009 (0.012)	-1347.38	0.959 (0.040)	0.000 (0.000)	0.009 (0.012)	-1347.38	N	0.777 (0.179)	0.000 (0.000)	0.000 (0.000)	0.216 (0.214)	-1344.69	N
UK	C	0.914 (0.036)	0.043 (0.019)	-1211.24	0.896 (0.045)	0.057 (0.036)	0.046 (0.019)	-1210.72	N	0.904 (0.031)	0.000 (0.000)	0.035 (0.018)	0.061 (0.030)	-1209.51	N
<i>Latin America</i>															
ARG	N	0.342 (0.155)	0.179 (0.095)	-1580.97	0.284 (0.330)	0.085 (0.390)	0.189 (0.117)	-1580.95	N	0.284 (0.330)	0.085 (0.390)	0.189 (0.116)	0.000 (0.000)	-1580.95	N
BRA	N	0.934 (0.055)	0.019 (0.016)	-1509.59	0.931 (0.056)	0.049 (0.049)	0.020 (0.015)	-1509.52	N	0.931 (0.056)	0.049 (0.049)	0.020 (0.015)	0.000 (0.000)	-1509.52	N
CHI	N	0.549 (0.716)	0.041 (0.093)	-1275.88	0.000 (0.000)	0.845 (0.256)	0.102 (0.117)	-1275.32	N	0.000 (0.000)	0.845 (0.255)	0.102 (0.117)	0.000 (0.000)	-1275.32	N
MEX	N	0.932 (0.063)	0.000 (0.000)	-1439.20	0.942 (0.039)	0.007 (0.010)	0.000 (0.000)	-1439.20	N	0.942 (0.037)	0.008 (0.017)	0.000 (0.000)	0.000 (0.000)	-1439.20	N
<i>North America</i>															
CAN	N	0.965 (0.021)	0.000 (0.000)	-1204.91	0.968 (0.019)	0.010 (0.017)	0.000 (0.000)	-1204.91	N	0.968 (0.019)	0.009 (0.015)	0.000 (0.000)	0.000 (0.000)	-1204.91	N
US	N	0.912 (0.033)	0.000 (0.000)	-1381.80	0.909 (0.046)	0.019 (0.122)	0.000 (0.000)	-1381.80	N	0.909 (0.044)	0.019 (0.083)	0.000 (0.000)	0.000 (0.000)	-1381.80	N
<i>Africa</i>															
SA	C	0.230 (1.651)	0.100 (0.158)	-1312.01	0.230 (1.665)	0.000 (0.000)	0.100 (0.160)	-1312.01	N	0.230 (1.658)	0.000 (0.000)	0.100 (0.159)	0.000 (0.000)	-1312.01	N

Panel B: Results for two-day average returns based on local currencies

	z-test	Model 1: DCC Model			Model 2: Modified DCC Model A				?	Model 3: Modified DCC Model B					
		δ	γ	LL	δ	δ^c	γ	LL		δ	δ^c	γ	γ^c	LL	?
<i>Asia</i>															
AUS	N	0.541 (0.310)	0.084 (0.074)	-684.42	0.541 (0.310)	0.000 (0.000)	0.084 (0.074)	-684.42	N	0.541 (0.310)	0.000 (0.000)	0.084 (0.074)	0.000 (0.000)	-684.42	N
INA	N	0.936 (0.042)	0.009 (0.016)	-930.97	0.936 (0.042)	0.000 (0.000)	0.009 (0.016)	-930.97	N	0.936 (0.042)	0.000 (0.000)	0.009 (0.016)	0.000 (0.000)	-930.97	N
IND	N	0.898 (0.107)	0.044 (0.027)	-902.88	0.898 (0.107)	0.000 (0.000)	0.044 (0.027)	-902.88	N	0.902 (0.121)	0.000 (0.000)	0.042 (0.031)	0.009 (0.043)	-902.86	N
JAP	N	0.156 (0.418)	0.031 (0.053)	-744.12	0.156 (0.418)	0.000 (0.000)	0.031 (0.053)	-744.12	N	0.156 (0.372)	0.000 (0.000)	0.031 (0.053)	0.000 (0.000)	-744.12	N
KOR	N	0.318 (0.216)	0.033 (0.049)	-996.07	0.318 (0.216)	0.000 (0.000)	0.033 (0.049)	-996.07	N	0.318 (0.216)	0.000 (0.000)	0.033 (0.049)	0.000 (0.000)	-996.07	N
MAL	C	0.991 (0.014)	0.002 (0.008)	-793.58	0.991 (0.014)	0.000 (0.000)	0.002 (0.008)	-793.58	N	0.954 (0.044)	0.010 (0.038)	0.000 (0.000)	0.036 (0.031)	-792.67	N
PHI	C	0.858 (0.049)	0.074 (0.028)	-850.49	0.211 (0.267)	0.681 (0.271)	0.107 (0.040)	-848.14	C	0.819 (0.089)	0.000 (0.000)	0.047 (0.028)	0.134 (0.085)	-846.46	C
SIN	C	0.896 (0.054)	0.033 (0.020)	-769.94	0.896 (0.054)	0.000 (0.000)	0.033 (0.020)	-769.94	N	0.880 (0.126)	0.000 (0.000)	0.024 (0.022)	0.045 (0.059)	-769.23	N
TWN	N	0.935 (0.053)	0.000 (0.000)	-994.74	0.934 (0.055)	0.002 (0.089)	0.000 (0.000)	-994.74	N	0.936 (0.053)	0.001 (0.026)	0.000 (0.000)	0.000 (0.000)	-994.74	N
THA	N	0.986 (0.007)	0.007 (0.008)	-1106.14	0.986 (0.007)	0.000 (0.000)	0.007 (0.008)	-1106.14	N	0.986 (0.007)	0.000 (0.000)	0.007 (0.008)	0.000 (0.000)	-1106.14	N
<i>Europe</i>															
BEL	C	0.959 (0.027)	0.014 (0.014)	-606.94	0.955 (0.034)	0.031 (0.033)	0.014 (0.013)	-606.91	N	0.957 (0.029)	0.000 (0.000)	0.013 (0.014)	0.028 (0.083)	-606.88	N
FRA	C	0.928 (0.032)	0.012 (0.017)	-751.45	0.899 (0.054)	0.085 (0.056)	0.016 (0.016)	-751.21	N	0.831 (0.126)	0.000 (0.000)	0.000 (0.000)	0.136 (0.129)	-750.37	N
GER	N	0.858 (0.062)	0.068 (0.031)	-715.44	0.858 (0.062)	0.000 (0.000)	0.068 (0.031)	-715.44	N	0.858 (0.062)	0.000 (0.000)	0.068 (0.031)	0.000 (0.000)	-715.44	N
ITA	C	0.790 (0.107)	0.048 (0.030)	-888.13	0.764 (0.119)	0.182 (0.105)	0.054 (0.035)	-887.85	N	0.747 (0.088)	0.000 (0.000)	0.046 (0.031)	0.207 (0.085)	-886.51	N
NET	C	0.967 (0.108)	0.016 (0.027)	-762.15	0.933 (0.136)	0.044 (0.116)	0.023 (0.025)	-762.08	N	0.909 (0.124)	0.000 (0.000)	0.024 (0.018)	0.066 (0.116)	-761.72	N
RUS	C	0.807 (0.109)	0.097 (0.054)	-1239.91	0.795 (0.151)	0.101 (0.132)	0.097 (0.064)	-1239.74	N	0.803 (0.131)	0.013 (0.242)	0.093 (0.057)	0.056 (0.176)	-1239.68	N
SPA	C	0.776 (0.144)	0.029 (0.040)	-786.20	0.790 (0.089)	0.183 (0.084)	0.027 (0.030)	-785.91	N	0.789 (0.089)	0.184 (0.084)	0.027 (0.030)	0.000 (0.000)	-785.91	N
SWE	C	0.912 (0.085)	0.016 (0.025)	-783.67	0.865 (0.108)	0.114 (0.105)	0.021 (0.025)	-783.51	N	0.863 (0.109)	0.115 (0.106)	0.021 (0.025)	0.000 (0.000)	-783.51	N
SWI	C	0.976 (0.030)	0.000 (0.000)	-726.08	0.983 (0.031)	0.001 (0.211)	0.000 (0.000)	-726.08	N	0.664 (0.289)	0.001 (0.027)	0.000 (0.000)	0.138 (0.192)	-725.09	N

UK	C	0.903 (0.029)	0.045 (0.024)	-597.29	0.890 (0.033)	0.064 (0.027)	0.046 (0.022)	-596.74	N	0.901 (0.026)	0.000 (0.000)	0.037 (0.021)	0.062 (0.025)	-596.27	N
<i>Latin America</i>															
ARG	N	0.828 (0.136)	0.070 (0.041)	-957.17	0.828 (0.136)	0.000 (0.000)	0.070 (0.041)	-957.17	N	0.828 (0.136)	0.000 (0.000)	0.070 (0.041)	0.000 (0.000)	-957.17	N
BRA	N	0.934 (0.057)	0.018 (0.016)	-894.30	0.934 (0.057)	0.000 (0.000)	0.018 (0.016)	-894.30	N	0.934 (0.057)	0.000 (0.000)	0.018 (0.016)	0.000 (0.000)	-894.30	N
CHI	N	0.000 (0.000)	0.121 (0.080)	-662.39	0.000 (0.000)	0.028 (0.266)	0.122 (0.088)	-662.38	N	0.000 (0.000)	0.028 (0.253)	0.122 (0.087)	0.000 (0.000)	-662.38	N
MEX	N	0.962 (0.010)	0.000 (0.000)	-819.73	0.962 (0.010)	0.004 (0.011)	0.000 (0.000)	-819.73	N	0.962 (0.010)	0.005 (0.020)	0.000 (0.000)	0.000 (0.000)	-819.73	N
<i>North America</i>															
CAN	N	0.797 (0.070)	0.026 (0.044)	-585.97	0.797 (0.070)	0.000 (0.000)	0.026 (0.044)	-585.97	N	0.821 (0.053)	0.111 (0.066)	0.018 (0.038)	0.049 (0.039)	-585.66	N
US	N	0.848 (0.058)	0.024 (0.024)	-755.33	0.850 (0.057)	0.000 (0.000)	0.024 (0.024)	-755.33	N	0.842 (0.101)	0.000 (0.000)	0.014 (0.029)	0.034 (0.052)	-755.07	N
<i>Africa</i>															
SA	C	0.025 (0.322)	0.215 (0.084)	-713.77	0.026 (0.338)	0.000 (0.000)	0.215 (0.084)	-713.77	N	0.025 (0.321)	0.000 (0.000)	0.215 (0.084)	0.000 (0.000)	-713.77	N

Table 5

The z-test results for 1994 Mexican peso crisis

This table presents the z-test results of contagion for the 1994 Mexico Peso crisis. We specify the univariate GARCH (1,1) process to capture the heteroscedasticity of returns. Correlations are between daily returns of Mexico index in calendar time t and those of the Asia and Europe indices in the calendar time $t + 1$, and those of North America indices in the calendar time t . The stable period is from January 1, 1993 to December 18, 1994, while the turmoil period is from December 19, 1994 to December 31, 1994. The full period includes both the stable and turmoil periods. The test statistics are for one-sided tests examining if the correlation coefficient during the turmoil period is greater than during the stable period. The p-values of the test statistics are reported in parentheses. “C” means a contagion with the test statistic significant at the 5% level, while “N” indicates that the test statistic is insignificant at the 5% level and therefore no contagion occurred

Country	Daily Returns					Two-day Moving Average Returns				
	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?
<i>Asia</i>										
Australia	0.101	-0.875	0.125	-3.83	N	0.139	0.277	0.123	0.38	N
Hong Kong	0.090	0.074	0.080	-0.04	N	0.106	-0.496	0.056	-1.71	N
India	-0.059	-0.163	-0.072	-0.28	N	-0.106	0.318	-0.073	1.14	N
Indonesia	0.083	-0.313	0.100	-1.07	N	0.121	-0.111	0.082	-0.61	N
Japan	-0.030	0.405	-0.044	1.21	N	-0.068	0.035	-0.059	0.27	N
Korea	0.094	-0.169	0.105	-0.70	N	0.119	-0.041	0.092	-0.42	N
Malaysia	0.016	0.259	0.042	0.65	N	0.103	-0.526	0.047	-1.81	N
Philippines	0.033	0.548	0.064	1.53	N	0.109	-0.402	0.061	-1.41	N
Singapore	0.032	0.411	0.106	1.06	N	0.119	0.008	0.087	-0.29	N
Taiwan	0.035	0.343	0.076	0.84	N	0.093	0.057	0.073	-0.10	N
Thailand	-0.003	-0.355	0.049	-0.97	N	0.082	-0.399	0.050	-1.33	N
<i>Europe</i>										
Belgium	0.092	0.400	0.108	0.87	N	0.113	0.324	0.097	0.58	N
France	0.043	0.418	0.139	1.06	N	0.158	0.154	0.128	-0.01	N
Germany	0.045	0.360	0.077	0.87	N	0.080	0.192	0.061	0.30	N
Italy	0.044	0.382	-0.022	0.94	N	0.008	-0.271	-0.022	-0.75	N
Netherlands	0.077	0.526	0.097	1.33	N	0.116	-0.126	0.074	-0.64	N
Spain	0.052	0.096	0.213	0.12	N	0.159	0.708	0.192	1.90	C
Sweden	0.095	0.793	0.062	2.58	C	0.061	-0.279	0.029	-0.91	N
Switzerland	0.084	0.458	0.082	1.08	N	0.094	-0.345	0.047	-1.19	N
U.K.	0.052	0.001	0.176	-0.13	N	0.205	-0.055	0.151	-0.69	N
<i>Latin America</i>										
Argentina	0.330	0.480	0.310	0.47	N	0.324	0.447	0.306	0.38	N
Brazil	0.181	0.754	0.209	2.10	C	0.175	0.754	0.206	2.11	C
Chile	0.214	0.600	0.220	1.25	N	0.197	0.737	0.227	1.96	C
<i>North America</i>										
Canada	0.231	-0.164	0.155	-1.05	N	0.212	0.020	0.159	-0.51	N
U.S.	0.227	-0.379	0.144	-1.65	N	0.230	-0.431	0.150	-1.83	N
<i>Africa</i>										
S. Africa	-0.017	-0.223	0.040	-0.55	N	0.030	0.255	0.028	0.61	N

Table 6

Time-Varying Conditional Correlation Test of the 1994 Mexican Peso Crisis for Returns Based on U.S. Dollars

The likelihood ratio (LR) tests of financial contagion are based on the Engle (2002)'s dynamic conditional correlation (DCC) model as a restricted model and the two modified DCC models as unrestricted models. The models are specified as:

Model 1(DCC model): $Q_t = (1 - \delta - \gamma)\bar{Q} + \delta Q_{t-1} + \gamma v_{t-1}v_{t-1}'$

Model 2 (Modified DCC model A): $Q_t = (1 - \delta - D\delta^C - \gamma)\bar{Q} + (\delta + D\delta^C)Q_{t-1} + \gamma v_{t-1}v_{t-1}'$

Model 3 (Modified DCC model B): $Q_t = (1 - \delta - D\delta^C - \gamma - D\gamma^C)\bar{Q} + (\delta + D\delta^C)Q_{t-1} + (\gamma + D\gamma^C)v_{t-1}v_{t-1}'$,

where \bar{Q} is the unconditional covariance matrix of the standardized residual vector v_t , and D is a dummy variable taking value 1 for the crisis period and 0 for the stable period. The stable period is from January 1, 1993 to December 18, 1994 and the crisis period is from December 19, 1994 to December 31, 1994. The test hypotheses for the model 1 and model 2 are $H_0 : \delta^C = 0$ and $H_0 : \delta^C = \gamma^C = 0$, respectively. “z-test” refers to the results of conventional z-test of contagion, and “N” stands for no contagion and “C” for contagion. “?” refers to the LR test results of contagion. “LL” is the log likelihood value of the estimated DCC models. We use the Constrained Maximum Likelihood (CML) module in GAUSS. The Bollerslev-Wooldridge heteroscedastic-consistent standard errors are reported in parentheses.

Panel A: Results for daily returns based on U.S. dollars															
z-test		Model 1: DCC Model			Model 2: Modified DCC Model A				?	Model 3: Modified DCC Model B					
		δ	γ	LL	δ	δ^C	γ	LL		δ	δ^C	γ	γ^C	LL	?
		<i>Asia</i>													
AUS	N	0.951 (0.049)	0.025 (0.017)	-1689.88	0.450 (0.659)	0.426 (0.568)	0.123 (0.104)	-1688.87	N	0.638 (0.493)	0.082 (0.471)	0.072 (0.083)	0.208 (0.074)	-1687.57	N
HK	N	0.969 (0.019)	0.017 (0.008)	-1873.73	0.969 (0.019)	0.000 (0.000)	0.017 (0.008)	-1873.73	N	0.969 (0.019)	0.000 (0.000)	0.017 (0.008)	0.000 (0.000)	-1873.73	N
INA	N	0.925 (0.131)	0.000 (0.000)	-1839.51	0.925 (0.130)	0.000 (0.000)	0.000 (0.000)	-1839.51	N	0.926 (0.130)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1839.51	N
IND	N	0.972 (0.006)	0.023 (0.007)	-1715.25	0.971 (0.007)	0.005 (0.008)	0.023 (0.008)	-1715.24	N	0.971 (0.007)	0.005 (0.008)	0.023 (0.008)	0.000 (0.000)	-1715.25	N
JAP	N	0.647 (0.087)	0.053 (0.023)	-1693.22	0.647 (0.087)	0.000 (0.000)	0.053 (0.023)	-1693.22	N	0.647 (0.087)	0.000 (0.000)	0.053 (0.023)	0.000 (0.000)	-1693.22	N
KOR	N	0.962 (0.018)	0.010 (0.013)	-1821.88	0.962 (0.018)	0.000 (0.000)	0.010 (0.013)	-1821.88	N	0.962 (0.018)	0.000 (0.000)	0.010 (0.013)	0.000 (0.000)	-1821.88	N
MAL	N	0.941 (0.017)	0.000 (0.000)	-1779.67	0.941 (0.017)	0.000 (0.000)	0.000 (0.000)	-1779.67	N	0.941 (0.018)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1779.67	N
PHI	N	0.976 (0.070)	0.000 (0.000)	-1815.12	0.976 (0.074)	0.000 (0.000)	0.000 (0.000)	-1815.12	N	0.976 (0.068)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1815.12	N
SIN	N	0.976 (0.008)	0.014 (0.007)	-1576.19	0.976 (0.008)	0.000 (0.000)	0.014 (0.007)	-1576.19	N	0.976 (0.008)	0.000 (0.000)	0.014 (0.007)	0.000 (0.000)	-1576.19	N
TWN	N	0.945 (0.105)	0.000 (0.000)	-1976.01	0.953 (0.062)	0.000 (0.000)	0.000 (0.000)	-1976.01	N	0.953 (0.075)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1976.01	N

THA	N	0.692 (0.140)	0.085 (0.046)	-1870.48	0.692 (0.140)	0.000 (0.000)	0.085 (0.046)	-1870.48	N	0.703 (0.158)	0.000 (0.000)	0.082 (0.050)	0.025 (0.047)	-1870.45	N
<i>Europe</i>															
BEL	N	0.915 (0.056)	0.019 (0.027)	-1503.29	0.915 (0.056)	0.000 (0.000)	0.019 (0.027)	-1503.29	N	0.915 (0.056)	0.000 (0.000)	0.019 (0.027)	0.000 (0.000)	-1503.29	N
FRA	N	0.948 (0.034)	0.000 (0.000)	-1604.78	0.947 (0.034)	0.000 (0.000)	0.000 (0.000)	-1604.78	N	0.946 (0.036)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1604.78	N
GER	N	0.907 (0.063)	0.014 (0.024)	-1597.91	0.904 (0.065)	0.048 (0.228)	0.013 (0.024)	-1597.90	N	0.904 (0.065)	0.048 (0.225)	0.013 (0.024)	0.000 (0.000)	-1597.90	N
ITA	N	0.959 (0.114)	0.000 (0.000)	-1872.50	0.958 (0.118)	0.000 (0.000)	0.000 (0.000)	-1872.50	N	0.958 (0.113)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1872.50	N
NET	N	0.943 (0.067)	0.000 (0.000)	-1468.00	0.942 (0.042)	0.000 (0.000)	0.000 (0.000)	-1468.00	N	0.941 (0.039)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1468.00	N
SPA	N	0.946 (0.067)	0.000 (0.000)	-1708.06	0.946 (0.063)	0.000 (0.000)	0.000 (0.000)	-1708.06	N	0.945 (0.061)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1708.06	N
SWE	C	0.974 (0.015)	0.010 (0.010)	-1776.28	0.974 (0.015)	0.000 (0.000)	0.010 (0.010)	-1776.28	N	0.974 (0.015)	0.000 (0.000)	0.010 (0.010)	0.000 (0.000)	-1776.28	N
SWI	N	0.985 (0.025)	0.000 (0.000)	-1589.00	0.984 (0.031)	0.000 (0.000)	0.000 (0.000)	-1589.00	N	0.983 (0.033)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1589.00	N
UK	N	0.963 (0.027)	0.012 (0.012)	-1533.41	0.963 (0.027)	0.025 (0.023)	0.012 (0.011)	-1533.40	N	0.967 (0.025)	0.000 (0.000)	0.010 (0.012)	0.022 (0.020)	-1533.29	N
<i>L. America</i>															
ARG	N	0.955 (0.029)	0.026 (0.014)	-1887.16	0.955 (0.029)	0.019 (0.019)	0.026 (0.014)	-1887.15	N	0.955 (0.029)	0.019 (0.019)	0.026 (0.014)	0.000 (0.000)	-1887.15	N
BRA	C	0.966 (0.017)	0.021 (0.010)	-2324.12	0.966 (0.018)	0.012 (0.012)	0.021 (0.010)	-2324.11	N	0.966 (0.016)	0.000 (0.000)	0.021 (0.009)	0.014 (0.012)	-2323.93	N
CHI	N	0.916 (0.034)	0.044 (0.020)	-1707.91	0.916 (0.034)	0.000 (0.000)	0.044 (0.020)	-1707.91	N	0.916 (0.034)	0.000 (0.000)	0.044 (0.020)	0.000 (0.000)	-1707.91	N
<i>N. America</i>															
CAN	N	0.850 (0.107)	0.047 (0.035)	-1422.14	0.847 (0.114)	0.108 (0.104)	0.045 (0.029)	-1422.06	N	0.842 (0.149)	0.000 (0.000)	0.041 (0.039)	0.048 (0.069)	-1421.96	N
US	N	0.952 (0.038)	0.025 (0.019)	-1355.89	0.945 (0.059)	0.028 (0.037)	0.027 (0.025)	-1355.78	N	0.944 (0.058)	0.000 (0.000)	0.025 (0.023)	0.031 (0.041)	-1355.70	N
<i>Africa</i>															
SA	N	0.965 (0.117)	0.000 (0.000)	-1682.30	0.965 (0.116)	0.001 (0.145)	0.000 (0.000)	-1682.30	N	0.972 (0.041)	0.005 (0.046)	0.000 (0.000)	0.023 (0.026)	-1682.16	N

Panel B: Results for two-day average returns based on U.S. dollars

	z-test	Model 1: DCC Model			Model 2: Modified DCC Model A				?	Model 3: Modified DCC Model B					
		δ	γ	LL	δ	δ^C	γ	LL		δ	δ^C	γ	γ^C	LL	?
<i>Asia</i>															
AUS	N	0.961 (0.023)	0.008 (0.012)	-1026.85	0.961 (0.023)	0.031 (0.022)	0.008 (0.012)	-1026.84	N	0.962 (0.023)	0.005 (0.804)	0.007 (0.013)	0.016 (0.188)	-1026.84	N
HK	N	0.862 (0.094)	0.040 (0.024)	-1211.94	0.851 (0.100)	0.108 (0.092)	0.040 (0.022)	-1211.87	N	0.851 (0.101)	0.108 (0.093)	0.040 (0.022)	0.000 (0.000)	-1211.87	N
INA	N	0.835 (0.067)	0.028 (0.019)	-1189.56	0.840 (0.099)	0.093 (0.876)	0.027 (0.027)	-1189.56	N	0.840 (0.099)	0.092 (0.874)	0.027 (0.027)	0.000 (0.000)	-1189.56	N
IND	N	0.965 (0.022)	0.000 (0.000)	-1063.50	0.965 (0.022)	0.000 (0.000)	0.000 (0.000)	-1063.50	N	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.594 (1.055)	-1062.51	N
JAP	N	0.971 (0.016)	0.000 (0.000)	-1020.68	0.971 (0.015)	0.000 (0.000)	0.000 (0.000)	-1020.68	N	0.971 (0.015)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1020.68	N
KOR	N	0.949 (0.015)	0.000 (0.000)	-1165.85	0.949 (0.015)	0.000 (0.000)	0.000 (0.000)	-1165.85	N	0.949 (0.018)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-1165.85	N
MAL	N	0.390 (0.195)	0.219 (0.078)	-1117.16	0.369 (0.270)	0.041 (0.239)	0.221 (0.078)	-1117.15	N	0.322 (0.141)	0.000 (0.000)	0.214 (0.073)	0.130 (0.117)	-1116.90	N
PHI	N	0.025 (0.391)	0.138 (0.063)	-1148.50	0.000 (0.000)	0.595 (0.362)	0.121 (0.070)	-1148.26	N	0.000 (0.000)	0.595 (0.362)	0.121 (0.070)	0.000 (0.000)	-1148.26	N
SIN	N	0.949 (0.036)	0.026 (0.018)	-911.61	0.949 (0.036)	0.000 (0.000)	0.026 (0.018)	-911.61	N	0.949 (0.036)	0.000 (0.000)	0.026 (0.018)	0.000 (0.000)	-911.61	N
TWN	N	0.983 (0.026)	0.001 (0.006)	-1311.57	0.982 (0.029)	0.018 (0.029)	0.001 (0.006)	-1311.57	N	0.982 (0.028)	0.018 (0.028)	0.001 (0.006)	0.000 (0.000)	-1311.57	N
THA	N	0.886 (0.067)	0.019 (0.019)	-1209.59	0.866 (0.121)	0.114 (0.121)	0.020 (0.018)	-1209.51	N	0.905 (0.061)	0.000 (0.000)	0.011 (0.020)	0.066 (0.039)	-1209.24	N
<i>Europe</i>															
BEL	N	0.961 (0.034)	0.000 (0.000)	-850.59	0.960 (0.038)	0.000 (0.000)	0.000 (0.000)	-850.59	N	0.960 (0.037)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-850.59	N
FRA	N	0.975 (0.036)	0.000 (0.000)	-944.10	0.974 (0.038)	0.023 (0.047)	0.000 (0.000)	-944.00	N	0.974 (0.038)	0.023 (0.047)	0.000 (0.000)	0.000 (0.000)	-944.00	N
GER	N	0.953 (0.034)	0.000 (0.000)	-937.96	0.952 (0.035)	0.000 (0.000)	0.000 (0.000)	-937.96	N	0.942 (0.061)	0.001 (0.018)	0.000 (0.000)	0.057 (0.065)	-937.80	N
ITA	N	0.979 (0.018)	0.003 (0.009)	-1219.20	0.978 (0.025)	0.019 (0.027)	0.003 (0.009)	-1219.19	N	0.981 (0.014)	0.004 (0.023)	0.001 (0.011)	0.014 (0.026)	-1219.13	N
NET	N	0.920 (0.053)	0.000 (0.000)	-816.35	0.920 (0.052)	0.000 (0.000)	0.000 (0.000)	-816.35	N	0.927 (0.063)	0.007 (0.026)	0.000 (0.000)	0.065 (0.071)	-815.90	N
SPA	C	0.874 (0.096)	0.034 (0.028)	-1041.33	0.835 (0.116)	0.127 (0.106)	0.038 (0.028)	-1041.08	N	0.892 (0.272)	0.039 (0.297)	0.024 (0.046)	0.045 (0.091)	-1040.88	N
SWE	N	0.887 (0.050)	0.047 (0.022)	-1114.12	0.887 (0.051)	0.057 (0.134)	0.046 (0.022)	-1114.11	N	0.887 (0.051)	0.057 (0.134)	0.046 (0.022)	0.000 (0.000)	-1114.11	N
SWI	N	0.979 (0.025)	0.001 (0.009)	-922.12	0.979 (0.023)	0.020 (0.023)	0.001 (0.008)	-922.12	N	0.935 (0.058)	0.000 (0.000)	0.000 (0.000)	0.064 (0.058)	-921.50	N

UK	N	0.935 (0.030)	0.000 (0.000)	-864.21	0.935 (0.031)	0.000 (0.000)	0.000 (0.000)	-864.21	N	0.901 (0.130)	0.000 (0.000)	0.000 (0.000)	0.077 (0.029)	-863.01	N
<i>L. America</i>															
ARG	N	0.970 (0.012)	0.023 (0.009)	-1226.63	0.970 (0.012)	0.000 (0.000)	0.023 (0.009)	-1226.63	N	0.970 (0.012)	0.000 (0.000)	0.023 (0.009)	0.000 (0.000)	-1226.63	N
BRA	C	0.975 (0.016)	0.017 (0.010)	-1651.45	0.974 (0.016)	0.009 (0.011)	0.017 (0.010)	-1651.43	N	0.973 (0.015)	0.000 (0.000)	0.016 (0.009)	0.010 (0.012)	-1651.30	N
CHI	C	0.923 (0.032)	0.035 (0.022)	-1044.27	0.921 (0.034)	0.043 (0.032)	0.035 (0.021)	-1044.22	N	0.932 (0.034)	0.007 (0.052)	0.029 (0.025)	0.032 (0.044)	-1044.07	N
<i>N. America</i>															
CAN	N	0.916 (0.030)	0.043 (0.022)	-761.28	0.916 (0.030)	0.000 (0.000)	0.043 (0.022)	-761.28	N	0.916 (0.030)	0.000 (0.000)	0.043 (0.022)	0.000 (0.000)	-761.28	N
US	N	0.961 (0.020)	0.023 (0.011)	-693.30	0.958 (0.024)	0.018 (0.017)	0.023 (0.011)	-693.21	N	0.956 (0.029)	0.000 (0.000)	0.022 (0.012)	0.021 (0.024)	-693.12	N
<i>Africa</i>															
SA	N	0.928 (0.197)	0.000 (0.000)	-1011.40	0.928 (0.198)	0.000 (0.000)	0.000 (0.000)	-1011.40	N	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.244 (0.054)	-1009.75	N

Table 7

The Z-Test Results for 1987 U.S. Stock Market Crash

This table presents the z-test results of contagion for the 1987 U.S. stock market crash. We specify the univariate GARCH (1,1) process to capture the heteroscedasticity of returns. The stable period is from January 1, 1986 to October 16, 1987, and the turmoil period is from October 17, 1987 to December 4, 1987. The full period includes both the stable and turmoil periods. The test statistics are for one-sided tests examining if the correlation coefficient during the turmoil period is greater than during the stable period. The p-values of the test statistics are reported in parentheses. “C” means a contagion with the test statistic significant at the 5% level, while “N” indicates that the test statistic is insignificant at the 5% level and therefore no contagion occurred.

Country	Daily Returns					Two-day Moving Average Returns					
	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?	Stable period	Turmoil period	Full period	Z-Stat.	Contagion?	
	<i>Asia</i>										
Australia	0.110	0.822	0.571	5.67	C	-0.012	-0.078	-0.033	-0.36	N	
Hong Kong	0.211	0.024	0.106	-1.02	N	0.016	0.468	0.334	2.68	C	
Japan	0.182	0.790	0.475	4.77	C	0.096	0.064	0.085	-0.17	N	
	<i>Europe</i>										
France	0.249	0.064	0.162	-1.02	N	0.073	0.643	0.362	3.77	C	
Germany	0.276	0.361	0.302	0.51	N	0.089	0.463	0.256	2.25	C	
Netherlands	0.426	0.366	0.394	-0.38	N	0.261	0.612	0.477	2.43	C	
Switzerland	0.328	0.289	0.310	-0.23	N	0.060	0.695	0.431	4.36	C	
U.K.	0.214	0.479	0.352	1.64	C	0.206	0.480	0.360	1.71	C	
	<i>North America</i>										
Canada	0.574	0.753	0.693	1.79	C	0.576	0.734	0.680	1.53	N	

Table 8

Time-Varying Conditional Correlation Test of the 1987 U.S. Stock Market Crash for Returns Based on U.S. Dollars

The likelihood ratio (LR) tests of financial contagion are based on the Engle (2002)'s dynamic conditional correlation (DCC) model as a restricted model and the two modified DCC models as unrestricted models. The models are specified as:

Model 1(DCC model): $Q_t = (1 - \delta - \gamma)\bar{Q} + \delta Q_{t-1} + \gamma v_{t-1} v_{t-1}'$

Model 2 (Modified DCC model A): $Q_t = (1 - \delta - D\delta^C - \gamma)\bar{Q} + (\delta + D\delta^C)Q_{t-1} + \gamma v_{t-1} v_{t-1}'$

Model 3 (Modified DCC model B): $Q_t = (1 - \delta - D\delta^C - \gamma - D\gamma^C)\bar{Q} + (\delta + D\delta^C)Q_{t-1} + (\gamma + D\gamma^C)v_{t-1} v_{t-1}'$,

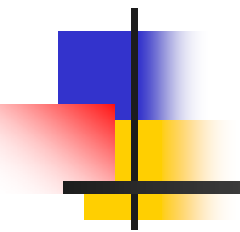
where \bar{Q} is the unconditional covariance matrix of the standardized residual vector v_t , and D is a dummy variable taking value 1 for the crisis period and 0 for the stable period. The stable period is from January 1, 1986 to October 16, 1987 and the crisis period is from October 17, 1987 to December 4, 1987. The test hypotheses for the model 1 and model 2 are $H_0 : \delta^C = 0$ and $H_0 : \delta^C = \gamma^C = 0$, respectively. “z-test” refers to the results of conventional z-test of contagion, and “N” stands for no contagion and “C” for contagion. “?” refers to the LR test results of contagion. “LL” is the log likelihood value of the estimated DCC models. We use the Constrained Maximum Likelihood (CML) module in GAUSS. The Bollerslev-Wooldridge heteroscedastic-consistent standard errors are reported in parentheses.

Panel A: Results for daily returns based on U.S. dollars															
z-test		Model 1: DCC Model			Model 2: Modified DCC Model A				?	Model 3: Modified DCC Model B					
		δ	γ	LL	δ	δ^C	γ	LL		δ	δ^C	γ	γ^C	LL	?
		<i>Asia</i>													
AUS	C	0.894 (0.116)	0.050 (0.040)	-1619.80	0.894 (0.116)	0.000 (0.000)	0.050 (0.040)	-1619.80	N	0.894 (0.116)	0.000 (0.000)	0.050 (0.040)	0.000 (0.000)	-1619.80	N
HK	N	0.969 (0.022)	0.000 (0.000)	-1667.25	0.966 (0.062)	0.012 (0.182)	0.000 (0.000)	-1667.25	N	0.966 (0.066)	0.012 (0.154)	0.000 (0.000)	0.000 (0.000)	-1667.25	N
JAP	C	0.367 (0.417)	0.152 (0.094)	-1594.88	0.367 (0.417)	0.000 (0.000)	0.152 (0.094)	-1594.88	N	0.001 (0.056)	0.000 (0.000)	0.085 (0.098)	0.218 (0.243)	-1594.29	N
		<i>Europe</i>													
FRA	N	0.979 (0.039)	0.000 (0.000)	-1563.51	0.979 (0.047)	0.001 (0.095)	0.000 (0.000)	-1563.51	N	0.980 (0.096)	0.002 (0.089)	0.000 (0.000)	0.000 (0.000)	-1563.51	N
GER	N	0.974 (0.014)	0.008 (0.006)	-1530.18	0.973 (0.014)	0.007 (0.097)	0.008 (0.007)	-1530.18	N	0.973 (0.014)	0.007 (0.099)	0.008 (0.007)	0.000 (0.000)	-1530.18	N
NET	N	0.981 (0.012)	0.000 (0.000)	-1394.69	0.981 (0.020)	0.018 (0.210)	0.000 (0.000)	-1394.69	N	0.980 (0.041)	0.017 (0.461)	0.000 (0.000)	0.000 (0.000)	-1394.69	N
SWI	N	0.966 (0.050)	0.000 (0.000)	-1471.20	0.966 (0.055)	0.005 (0.056)	0.000 (0.000)	-1471.20	N	0.966 (0.076)	0.005 (0.075)	0.000 (0.000)	0.000 (0.000)	-1471.20	N
UK	C	0.000 (0.000)	0.068 (0.044)	-1504.50	0.000 (0.000)	0.000 (0.000)	0.068 (0.044)	-1504.50	N	0.000 (0.000)	0.000 (0.000)	0.067 (0.089)	0.001 (0.104)	-1504.50	N
		<i>N. America</i>													
CAN	C	0.937 (0.044)	0.021 (0.021)	-1209.03	0.927 (0.058)	0.026 (0.051)	0.021 (0.024)	-1208.90	N	0.927 (0.057)	0.026 (0.051)	0.021 (0.024)	0.000 (0.000)	-1208.90	N

Panel B: Results for two-day average returns based on U.S. dollars

	z-test	Model 1: DCC Model			Model 2: Modified DCC Model A				?	Model 3: Modified DCC Model B					
		δ	γ	LL	δ	δ^c	γ	LL		δ	δ^c	γ	γ^c	LL	?
<i>Asia</i>															
AUS	N	0.931 (0.071)	0.000 (0.000)	-1035.10	0.934 (0.194)	0.054 (0.097)	0.000 (0.000)	-1035.10	N	0.936 (0.204)	0.053 (0.152)	0.000 (0.000)	0.000 (0.000)	-1035.10	N
HK	C	0.281 (0.071)	0.221 (0.074)	-1031.53	0.281 (0.071)	0.000 (0.000)	0.221 (0.074)	-1031.53	N	0.256 (0.113)	0.000 (0.000)	0.192 (0.108)	0.061 (0.186)	-1031.44	N
JAP	N	0.972 (0.018)	0.001 (0.010)	-1013.47	0.958 (0.029)	0.039 (0.031)	0.002 (0.006)	-1013.45	N	0.957 (0.033)	0.040 (0.035)	0.002 (0.006)	0.000 (0.000)	-1013.45	N
<i>Europe</i>															
FRA	C	0.889 (0.048)	0.031 (0.019)	-942.26	0.720 (0.324)	0.187 (0.317)	0.036 (0.023)	-941.62	N	0.720 (0.325)	0.186 (0.317)	0.036 (0.023)	0.000 (0.000)	-941.62	N
GER	C	0.821 (0.371)	0.023 (0.058)	-926.79	0.716 (0.129)	0.199 (0.128)	0.022 (0.043)	-926.39	N	0.716 (0.129)	0.199 (0.128)	0.022 (0.043)	0.000 (0.000)	-926.39	N
NET	C	0.910 (0.161)	0.028 (0.054)	-780.38	0.819 (0.179)	0.118 (0.187)	0.028 (0.056)	-779.95	N	0.819 (0.179)	0.117 (0.188)	0.028 (0.056)	0.000 (0.000)	-779.95	N
SWI	C	0.752 (0.119)	0.122 (0.086)	-852.24	0.740 (0.127)	0.024 (0.100)	0.122 (0.080)	-852.20	N	0.740 (0.127)	0.024 (0.099)	0.122 (0.080)	0.000 (0.000)	-852.20	N
UK	C	0.960 (0.030)	0.016 (0.022)	-875.92	0.949 (0.037)	0.034 (0.030)	0.016 (0.017)	-874.90	N	0.949 (0.037)	0.034 (0.030)	0.016 (0.018)	0.000 (0.000)	-874.90	N
<i>N. America</i>															
CAN	N	0.959 (0.033)	0.013 (0.014)	-598.39	0.957 (0.028)	0.031 (0.025)	0.011 (0.010)	-598.15	N	0.957 (0.028)	0.031 (0.025)	0.011 (0.010)	0.000 (0.000)	-598.15	N

Testing Financial Contagion with Time-Varying Correlation of Heteroscedastic Asset Returns



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Backgrounds

- International equity market contagion implies that a financial crisis from one country has a great influence on investor's pricing behavior, such that increasing the probability of another crisis in other countries.
 - 1987 US stock market crash
 - 1994 Mexican Peso crisis
 - 1997 Asian currency crisis

Theoretical explanations of financial contagion

- Either interpreting an excess co-movement as an equilibrium result of rational behavior of risk-averse investors in a market setting with frictions, such as information asymmetry, information heterogeneity, imperfect competition, wealth and borrowing constraints, risk-bearing capacity, etc.
- Or attribute excess co-movements to irrational decision-making by those same agents, such as herding, categorization, preferred habitat, etc.

Empirical Approach on Financial Contagion

- A conventional methodology of testing financial contagion is the constant correlation test, where financial contagion is defined as a significant increase in cross-market co-movements during the crises period relative to the normal period.
- King and Wadhvani (1990), Calvo and Reinhart (1996), Baig and Goldfajn (1998), Park and Song (2001), Chakrabarti and Roll (2002), Wongswan (2003) and Bekaert, Harvey and Ng (2005).

Heteroscedasticity Bias in Correlation Test

- Forbes and Rigobon (2002), Loretan and English (2000), and Boyer, Gibson, and Loretan (1999) argue that the conventional constant correlation test for contagion is considerably biased due to the heteroscedasticity inherent in asset returns.
- They show that return correlations can spuriously increase on a statistical ground when a market X become more volatile.

$$Y_t = \alpha + \beta X_t + \varepsilon_t \quad \rho = \frac{\sigma_{XY}}{\sigma_X \sigma_Y} = \bar{\beta} \frac{\sigma_X}{\sigma_Y}$$

- Forbes and Rigobon (2002) show that the previous result of contagion is reversed dramatically once the correlation is adjusted for the bias in the test.
- In contrast, Bartram and Wang (2005) and Corsetti, Pericoli and Sbracia (2005) pointed out that the adjustment causes the correlation test to be severely biased towards no contagion.

Economic Rationale

- International equity market investors respond to changing market riskiness through many different financial channels, and their reactions induce cross-market co-movements.
- We view the nature of the international investors' responses to market riskiness in terms of two important hypotheses:
 - Time-varying rational expectation hypothesis.
 - Stock market overreaction (psychology) hypothesis.

- Rational reactions as those induced by the risk-averse investors who systematically revise their expectations in response to changing volatility through various financial linkages. [**Time-varying rationality**]
- Irrational reactions as those responses induced by investors who overreact to changing volatility, with an extremely optimistic or pessimistic expectation. [**Stock market overreaction**]

- Due to the time-varying nature of the rational investors' revision in their expectation, cross-market co-movements are also time-varying, such that the conventional test using the constant correlation is not appropriate for testing financial contagion.
- With this time-varying nature of the cross market correlation correctly specified in the test for contagion, one can effectively avoid the statistical bias in the correlation test.
- Note that time-varying idea of equity market correlation is not new. Longin and Solnik (1995, 2001), Ramchand and Susmel (1998), Karolyi and Stulz (1996), and Ang and Chen (2002).

Implications to the test for contagion

- While Both rational and irrational responses are the sources of cross-market co-movements, we do not view any temporal changes in correlation dynamics resulting from time-varying rational reactions as contagion evidence.
- Only those responses with an extremely pessimistic expectation are more likely to cause financial contagion.

Main Points

- Heteroskedasticity in asset returns is not just a statistical bias in the correlation test for contagion, but rather it is an underlying force to induce time-varying cross-market co-movements, i.e., *economic importance*.
- We suggest that a substantial portion of cross market co-movements is attributed to the rational responses by risk-averse investors who systematically revise their expectation in responding to changing volatility.

- The contagion evidence reported by the studies using the constant correlation test might be partially attributed to an increase in cross-market correlation, which can be reasonably explained by risk-averse investors' rational pricing behavior, i.e., they actively adjust their investment positions to the high level of predictable volatility during periods of turmoil.
- We propose time-varying conditional correlation test for contagion, where the time-varying component of cross-market correlation be controlled as a predictable dynamics, such that only a sharp increase (a structural break) in correlation dynamics is assumed to be evidence of contagion.

Modeling Strategy

- Using the multivariate Dynamic Conditional Correlation (DCC) GARCH model by Engle (2002) as a base model, we capture the time-varying nature of the conditional correlation over the entire sample period.

$$r_t = E(r_t | \Omega_{t-1}) + \varepsilon_t \quad \varepsilon_t | \Omega_{t-1} \sim N(0, H_t)$$

$$Q_t = (1 - \sum_{r=1}^R \delta_r - \sum_{s=1}^S \gamma_s) \bar{Q} + \sum_{r=1}^R \delta_r Q_{t-r} + \sum_{s=1}^S \gamma_s (v_{t-s} v_{t-s}')$$

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1}, \quad H_t = D_t R_t D_t$$

- Then, using a dummy variable in the DCC model, we capture a structure break as contagion evidence in the dynamics of the time-varying conditional correlation during the crisis period.

Empirical Models

- Model 1 (H0): Bivariate DCC(1,1) GARCH(1,1) as a base model

$$r_{jt} = \mu_j + \rho r_{j,t-1} + a_j i_{jt} + b_j i_{US,t} + \varepsilon_{jt}$$

$$h_{jt} = \kappa_j + \alpha_j \varepsilon_{jt-1}^2 + \beta_j h_{jt-1}$$

$$Q_t = (1 - \delta - \gamma) \bar{Q} + \delta Q_{t-1} + \gamma (v_{t-1} v'_{t-1})$$

- Model 2 (H1): Modified bivariate DCC(1,1) GARCH(1,1) Model A

$$Q_t = (1 - \delta - \delta^c D - \gamma) \bar{Q} + (\delta + \delta^c D) Q_{t-1} + \gamma v_{t-1} v'_{t-1}$$

$$H_0 : \delta^c = 0$$

- Model 3 (H1): Modified bivariate DCC(1,1) GARCH(1,1) Model B

$$Q_t = (1 - \delta - \delta^c D - \gamma - \gamma^c D) \bar{Q} + (\delta + \delta^c D) Q_{t-1} + (\gamma + \gamma^c D) v_{t-1} v'_{t-1}$$

$$H_0 : \delta^c = \gamma^c = 0$$

Data

- 1997 Asian Crisis
 - Entire sample: Jan. 1, 1996 – Nov. 14, 1997
 - Stable period: Jan. 1, 1996 – Oct. 17, 1997
 - Crisis period: Oct.17, 1997 – Nov. 14, 1997
- 1994 Mexican Peso Crisis
 - Entire sample: Jan. 1, 1993 – Dec. 31, 1994
 - Stable period: Jan. 1, 1993 – Dec. 18, 1994
 - Crisis period: Dec.19, 1994 – Dec. 31, 1994
- 1987 US Stock market Crash
 - Entire sample: Jan. 1, 1986 – Dec. 4, 1987
 - Stable period: Jan. 1, 1986 – Oct.16, 1987
 - Crisis period: Oct.17, 1987 – Dec. 4, 1987

- Following Forbes and Rigobon (2002) and Corsetti et al. (2005), we also employed two-day rolling-average returns of each country.
- The use of the two-day average returns is effective in controlling the problem arising from the different time-zones of the international stock markets.
- The two-day return series exhibits a high degree of serial correlation for all countries. We remove serial correlations in the two-day rolling average returns by estimating AR(8) model for all series.
- After removing serial dependence, we estimate the DCC multivariate GARCH model on the resulting residuals.

1997 Asian Currency Crisis

	Z-test		Model 2		Model 3	
	Daily Ret	Two-day	Daily Ret	Two-day	Daily Ret	Two-day
<i>Asia</i>						
Australia	C	N	N	N	N	N
India	N	N	N	N	N	N
Indonesia	C	C	N	N	N	N
Japan	N	N	N	N	N	N
Korea	N	N	N	N	N	N
Malaysia	C	C	N	N	N	N
Philippines	C	C	N	C	C	C
Singapore	C	C	N	N	N	N
Taiwan	N	N	N	N	N	N
Thailand	N	N	N	N	N	N

	Z-test		Model 2		Model 3	
	Daily Ret	Two-day	Daily Ret	Two-day	Daily Ret	Two-day
<i>Europe</i>						
Belgium	N	N	N	N	N	N
France	C	C	N	N	N	N
Germany	C	N	N	N	N	N
Italy	C	C	N	C	C	N
Netherlands	C	N	N	N	N	N
Russia	C	C	N	N	N	N
Spain	C	N	N	N	N	N
Sweden	C	C	N	N	N	N
Switzerland	C	C	N	N	N	N
U.K.	C	C	N	N	N	N

	Z-test		Model 2		Model 3	
	Daily Ret	Two-day	Daily Ret	Two-day	Daily Ret	Two-day
<i>Latin America</i>						
Argentina	N	N	N	N	N	N
Brazil	N	N	N	N	N	N
Chile	C	N	N	N	N	N
Mexico	N	N	N	N	N	N
<i>North America</i>						
Canada	N	N	N	N	N	N
U.S.	N	N	N	N	N	N
<i>Africa</i>						
S. Africa	C	C	N	N	N	N

Main Findings & Conclusion

- The multivariate DCC GARCH model suggests there is a significant time-varying component in cross market co-movements, which can be captured by the dynamics of conditional correlation.
- Only the Philippines and Italy show evidence of contagion from the 1997 Asian crisis, and none of the countries considered in the test show contagion evidence from the 1994 Mexican peso crisis and 1987 U.S. stock market crash.
- High correlation during the crisis time reported as contagion evidence by the constant correlation test is mostly attributed to an increase in the cross-market co-movements resulting from those responses by risk-averse investors who systematically revise their expectations in response to their perceived future volatility during the crisis period.