

**East Asia and Europe During the 1997 Asian Collapse:  
A Clinical Study of a Financial Crisis**

By

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**Abstract**

Asian stock markets are compared with European markets before and during the 1997 Asian crisis. The clinical issue is whether regional inter-dependence became larger around the crisis, fomenting investor fears of contagion and reducing asset values because of lower diversification potential. Statistical measures are developed to aid in this inquiry. We find that European and East Asian countries were not susceptible to volatility contagion in the pre-crisis era but that susceptibility increased significantly in Asia with the onset of the crisis. Covariances, correlations, and volatilities increased from the pre-crisis to the crisis period in both regions, but the percentage increases were much larger in Asia. Diversification potential was better in Asia than in Europe before the crisis; this was reversed during the crisis. The observed decline in diversification potency in Asia is reason enough for large declines in asset values though one cannot prove, of course, that it was the cause rather than the effect of the crisis.

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## **East Asia and Europe During the 1997 Asian Collapse: A Clinical Study of a Financial Crisis**

### **1. Introduction**

On July 2, 1997 the Thai baht broke its peg to the US dollar. In the six months that followed, Thailand lost 65% of its stock market value in dollar terms, Hong Kong 33%, Indonesia 71%, Malaysia 57%, Philippines 58%, Singapore 24%, and South Korea 72%. Both currencies and local stock market indices plunged in most countries. Thailand lost about 33% of its local stock value, Hong Kong 32%, Indonesia 34%, Malaysia 42%, Philippines 32% Singapore 10%, and South Korea 44%. The nearly simultaneous misfortune of so many countries has raised questions about linkages among stock markets in general. How closely are stock markets in neighboring countries related? Are East Asian stock markets more closely connected than any other neighboring countries? Was the rapid spread of the crisis in Asia predictable from strong prior inter-relations or, to the contrary, did the crisis mark a break from the past? How have inter-linkages evolved over time? Finally, how is the international portfolio investor typically affected by the short-run co-movements of returns in various markets in a region, particularly when one or a few countries experiences a crisis?

To answer these questions, we require a method for characterizing co-movements of national stock returns within a region or a group of countries. Relations between pairs of countries have been studied often, but past literature provides scant guidance about how to measure the overall structure of relations within a group of countries. This paper develops a method for studying co-movements among a group of national stock markets. In doing so, it constructs some new statistical measures. The paper also tries to answer the questions raised in the previous paragraph by analyzing the regional interdependence among stock markets of East Asian countries during the mid-90s and by contrasting it to that among West European countries.

Prior to the crisis, there had been some empirical literature on the long-term linkages among Asian stock markets (e.g., Chung and Liu (1994)) but short-term co-movement and its stability had not been subjected to extensive inquiry. The crisis justifiably engendered theoretical and empirical research attempting to explain the phenomenon; yet little has been done

to compare co-movements of Asian markets before and after this landmark event. This subject, which seems of critical importance in understanding the crisis and averting future ones, is where we aim to make a contribution.

The paper is organized as follows. The next section summarizes the important research findings in the areas of stock market inter-linkages and East Asian financial markets. Section 3 describes the data to be examined. In section 4, we state the basic research questions and design some statistical tools useful in answering them. Section 5 presents the empirical evidence. Section 6 concludes and offers suggestions for future research.

## **2. Previous Literature**

Using the then newly developed method of co-integration, Kasa (1992) studied the long-term equilibrium relations among five developed capital markets and extracted a common trend that strikingly captured their movements. Subsequent contributions included Arshanapalli and Doukas (1993) and Chung and Liu (1994). Richards (1995), however, questioned Kasa's conclusions and argued that while national stock markets exhibit predictability, there is little evidence of co-integration.

Another branch of the literature has examined the evolution of correlation among a group of countries over time. Important contributions here include Kaplanis (1988), Koch and Koch (1991) and Longin and Solnik (1995). Kaplanis (1988) traced the stability of the co-movements among monthly stock index returns for ten industrial countries between 1967 and 1982; he found stability in correlations but not in covariances. Koch and Koch (1991) studied co-movements of daily returns in six industrialized and two developing countries between 1972 and 1987; they found strong interactions among markets on the same day and they also documented changes over time in the correlation structure. Among developed countries between 1960 and 1990, Longin and Solnik (1995) concluded that both covariances and correlations were unstable.

Hamao *et al* (1990), King and Wadhvani (1990) and others have investigated "spillovers" in volatility and expected returns from one country to another. The former used a GARCH model to measure spillover while the latter used contemporaneous correlations. Volatility spillover is an important concept because it attempts to identify directional causality

between disturbances in two countries. An extension and variation of this approach will be adopted hereafter.

Some studies have looked at East Asian countries in particular. Chung and Liu (1994) found that the US and five East Asian countries have co-integrated stock prices. So *et al* (1997) examined the volatility of and correlations among seven Southeast Asian stock markets between 1980 and 1991 and attempted to group countries into interconnected blocks.

The Asian crisis itself has elicited quite a few papers. The role of currency has received much attention, (see Kamin (1999), Fernald *et al.* (1999), and Masson (1999)). Banks and regulators have received their share of criticism, (See Kane (2000)) but Kho and Stulz find little evidence that banks as a group or the International Monetary Fund were prime culprits. Few papers have viewed the crisis from the perspective of an international portfolio investor, yet many, notably including the Malaysian prime minister (Mohamad (1997)), have blamed international fund managers for the crisis. Brown, Goetzmann, and Park [2000] counter this view in the case of hedge funds.

In a recent assessment of the literature, Chowdhry and Goyal [2000, p. 135] conclude that most theoretical explanations of the Asian crisis are “disappointing” in their “out-of-sample performance.” They call for an alternative diagnosis. Our clinical study responds by comparing the afflicted patient, East Asia, with a healthy Europe. We compare the relative strength of market linkages within each region and attempt to determine whether Asia’s linkages underwent fundamental change during the crisis.

### **3. Data**

The available data are daily close-to-close returns for indices of eight East Asian countries that experienced a crisis of some severity in 1997. Data were also collected for a matching sample of eight West European non-crisis countries. The Asian countries are Hong Kong, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan and Thailand while the European countries are France, Germany, Italy, the Netherlands, Portugal, Spain, Switzerland, and the United Kingdom. The two groups are of equal size for ease of comparison and the European matching sample consists simply of the largest countries augmented with two arbitrarily-chosen smaller countries for a total of eight.

Time zone differences within either region do not exceed two hours; hence, contemporaneous daily data can be employed in computing co-movements. Daily closing stock index levels in local currency are from DATASTREAM. The local currency stock index value is converted to dollars using the daily closing exchange rate obtained from the same source. Dollar returns are computed by using the formula  $\ln(P_t/P_{t-1})$  where  $P_t$  refers to the dollar value of the index at time  $t$ . The data cover five years from 12/31/93 to 12/31/98, 1305 daily returns. We rather arbitrarily selected July 2, 1997 to be the beginning of the Asian crisis. On this date occurred the first major devaluation, that of the Thai baht. There had been previous storm warnings, particularly a “speculative attack” on the baht in mid-May, but July 2 has been generally identified as the first time that a real crisis was apparent; (see, for instance, the chronology of the Asian crisis constructed by Nouriel Roubini<sup>1</sup>). Our data sample thus includes 392 observations during the crisis period and 913 points before.

Table 1 provides descriptive statistics of the dollar-valued returns for both groups of countries over the entire sample and for the pre-crisis and crisis sub-samples. While the Asian countries all experienced negative average returns during the crisis period, no European country shared that experience; indeed, returns were higher than in the pre-crisis period for every European country. Figure 2, Panel A plots the mean returns to emphasize just how different the crisis period was in the two regions. The volatility of returns went up in the crisis period for every single country in both regions. In Asia, volatility is roughly three times higher (on average) during the crisis period; in Europe, it is about 1.5 times higher. See Figure 2, Panel B.

#### **4. Research Questions and Statistical Tools**

Our research agenda can be captured in a few questions: How susceptible are countries to volatility spillover and how did this susceptibility change during the Asian crisis? What proportion of intertemporal changes in covariances among countries is attributable to changes in correlation and what proportion to changes in variance? How has the ability to diversify within a region evolved over time? Each of these questions is critically important to the international investor. Volatility spillover, or contagion, implies that countries will become more or less risky around the same time. Evolution of the covariance structure alters the available degree of

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<sup>1</sup> Internet address <http://www.stern.nyu.edu/~nroubini/asia/AsiaHomepage.html>

diversification and thus changes the risk/return tradeoff for portfolio investors. The mere possibility of either phenomenon has the potential to induce investor panic and could conceivably explain why dramatic declines in prices propagate throughout a region.

First, we look at volatility “spillover” from one market to another and seek to determine whether spillover intensity changed during the 1997 crisis. An increase in spillover intensity would be evidence of greater contagion around the crisis. This issue was investigated by King and Wadhvani (1990), among others, during the pandemic October 1987 crash. We change their now standard approach slightly so as to measure the overall susceptibility of countries within a region to volatility shocks imported from neighbors.

To measure volatility spillover, we regress weekly first differences of daily volatility (from dollar-denominated returns of a country’s stock index) on lagged values from other countries in the region. Specifically, the regression model is

$$\Delta\sigma_{i,t} = \alpha_i + \sum_{j \neq i} [\beta_{i,j} \Delta\sigma_{j,t-1} + \Delta\beta_{i,j} \delta_t \Delta\sigma_{j,t-1}] + \epsilon_{i,t} \quad (1)$$

where  $\sigma_{i,t}$  is the estimated volatility computed from daily dollar-valued returns during week  $t$  in country  $i$ ,  $\Delta\sigma_{i,t} = (\sigma_{i,t} - \sigma_{i,t-1})$  is the weekly first difference, and  $\delta_t$  is an indicator variable which is zero in the pre-crisis period and unity during the crisis period.

First, we test whether there is evidence of volatility spillover of the same magnitude spanning the pre-crisis and crisis periods. The test’s null hypothesis is that the  $\beta_{i,j}$  (as opposed to the slope changes,  $\Delta\beta_{i,j}$ ), are all zero. For each region, we estimate all eight regressions (1) as a system and construct a joint test; i.e.,

$$H_0: \beta_{i,j} = 0, (j \neq i, \forall i). \quad (2)$$

This involves a simultaneous test that 56 coefficients, seven slope coefficients in eight regional equations, are all insignificantly different from zero.

The “slope dummy” ( $\delta_t$ ) in (1) also allows us to test whether the 1997 Asian crisis was marked by a change in volatility spillover. The null hypothesis is

$$H_0: \Delta\beta_{i,j} = 0, (j \neq i, \forall i). \quad (3)$$

Note that we do not restrict the change in spillover susceptibility, if any, to be a particular sign, though one might intuitively anticipate an increase in susceptibility during a crisis.

Our second research question asks about return covariances among countries within a region and how those covariances changed near the crisis. The importance of the covariance to

the international portfolio investor can hardly be over-emphasized; mean-variance efficient portfolios are determined in large part by the covariance matrix. Consequently, significant change in the regional covariance structure can explain why investors might eschew all markets at once; the benefits of diversification within those markets has become less compelling.

We also hope to uncover the sources of changes in covariance. Independent but contemporaneous disturbances in different countries will affect covariance but not correlation. Sympathetic movements among stock markets will raise the correlation as well. Understanding the covariance structure requires a decomposition into correlation and variance; thus a decomposition is proposed and implemented this paper. The relative importance of one component over the other provides a better understanding of the nature of co-movements among the markets. We estimate whether correlation played the dominant role during the crisis and also whether the correlation/variance decomposition is significantly different in Asia and Europe.

To summarize information in the covariance matrix in a single number, we propose the geometric mean of absolute values of the covariance between every pair of countries in a region

( $\gamma_{\text{cov}} = [\prod_{i<j} |\text{cov}_{ij}|]^{1/m(m-1)/2}$ ; where  $m$  is the number of countries). A corresponding measure for

correlation is  $\gamma_{\text{corr}} = [\prod_{i<j} |\text{corr}_{ij}|]^{1/m(m-1)/2}$ . Finally, we compute the geometric mean of the

standard deviations of the individual returns ( $\gamma_{\sigma} = [\prod_{i=1}^m s_i]^{1/m}$ ). These measures not only capture

the information in the covariance and correlation matrices but are also connected by the simple identity<sup>2</sup>:  $\gamma_{\text{cov}} = \gamma_{\text{corr}} \gamma_{\sigma}^2$ . Thus, the log first difference between two periods is

$$\Delta \log \gamma_{\text{cov}} = \Delta \log \gamma_{\text{corr}} + \Delta \log \gamma_{\sigma}^2 \quad (4)$$

which provides a decomposition of covariance change into its volatility and correlation components. Note that log first differences are equivalent to percentage changes (continuously compounded) and are thus dimensionless. The relative importance of correlation can then be measured by

$$\eta = |\Delta \log \gamma_{\text{corr}}| / (|\Delta \log \gamma_{\text{corr}}| + |\Delta \log \gamma_{\sigma}^2|) \quad (5)$$

which is bound between 0 and 1. The higher (lower) the value of  $\eta$ , the greater is the contribution of correlation (volatility) to the change in covariance. Evolution of the  $\eta$  statistic should reveal points in time when correlation and variance were relatively more prominent causes of movements in covariance.

Geometric means  $\gamma_{\text{cov}}$  and  $\gamma_{\text{corr}}$  are intended to compactly summarize covariances and correlations of stock returns in the two regions. This does involve some loss of information as any single number necessarily would if it attempts to capture an array of numbers. Our justification is our focus on the general trend of inter-linkages within each regional group rather than on individual countries *per se*.

The evolution and stability of the correlation matrix of returns within a region is of fundamental importance given the crucial role of the correlation structure in portfolio formation. To measure the evolution of correlation matrices, we adopt a test statistic for the equality of two or more correlation matrices developed in Jennrich (1970). For any two  $p$ -variate sample correlation matrices  $R_1$  and  $R_2$  of sample size  $n_1$  and  $n_2$  respectively, the Jennrich  $\chi^2$  is given by

$$\mathbf{c}^2 = \frac{1}{2} \text{tr}(\mathbf{Z}^2) - \text{dg}'(\mathbf{Z})\mathbf{S}^{-1}\text{dg}(\mathbf{Z}) \quad (6)$$

where  $\mathbf{Z} = \mathbf{c}^{1/2}\bar{\mathbf{R}}^{-1}(\mathbf{R}_1 - \mathbf{R}_2)$ ,  $\bar{\mathbf{R}} = (n_1\mathbf{R}_1 + n_2\mathbf{R}_2)/(n_1 + n_2)$ ,  $\mathbf{c} = n_1n_2/(n_1 + n_2)$ , and  $\mathbf{S} = (\mathbf{d}_{ij} + \bar{r}_{ij}\bar{r}^{ij})$ .

Here  $\delta_{ij}$  is the Kronecker delta,  $\bar{r}_{ij}$  is an element of  $\bar{\mathbf{R}}$  and  $\bar{r}^{ij}$  is an element of  $\bar{\mathbf{R}}^{-1}$ . The expressions 'tr' and 'dg' refer to the trace and diagonal of a matrix respectively. If the true correlation matrices are equal,  $\mathbf{c}^2$  is distributed asymptotically as Chi-Square with  $p(p-1)/2$  degrees of freedom. Consequently, by computing correlation matrices from two different time periods, we can test whether they have changed; e.g., from the pre-crisis to the crisis period.

There is an alternative and perhaps more direct approach to measuring changes in investment opportunities around the crisis: calculate diversification potential directly. How well (in mean-variance terms) would an international investor have fared by creating an efficient allocation within a region? Would diversification be more potent in Asia or in Europe, before the crisis or thereafter? These questions are answered by the shape of the regional efficient frontier and in particular by its curvature. The more sharply curved the frontier, the less effective

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<sup>2</sup> This can easily be verified by expanding the expression for  $\gamma_{\text{corr}}$  and reorganizing the terms.

diversification. Hence estimated curvature provides a direct empirical measure of diversification potential, a measure which can be traced over time and compared across periods and regions.

The mathematics of the efficient frontier, (e.g., Roll, 1977) shows that the efficient frontier can be described by the equation,

$$\sigma_p^2 = (a - 2br_p + cr_p^2) / (ac - b^2) \quad (7)$$

where  $\sigma_p^2$  is the variance of efficient portfolio p and  $r_p$  is its mean return. The efficient set constants are given by  $a = E'V^{-1}E$ ,  $b = E'V^{-1}\mathbf{1}$ , and  $c = \mathbf{1}'V^{-1}\mathbf{1}$ , where E is the mean return vector of n assets, V is their variance-covariance matrix, and  $\mathbf{1}$  is the unit vector. With a little rearrangement, (7) can be written as:

$$(\sigma_p^2 - 1/c) = [c/(ac - b^2)](r_p - b/c)^2 \quad (8)$$

which is the equation for a parabola with curvature  $\partial^2(\sigma_p^2)/\partial(r_p)^2 \equiv C = 2c/(ac - b^2)$ . The average level of C and its evolution in the two geographic regions provide the direct measurement we seek of diversification potential.

Taken as a battery of statistics, the above empirical constructs should help bring out a comprehensive picture of the short-term relations among stock markets in East Asia and how they differ from those among European stock markets. We hope also that these constructs will augment methods for studying and characterizing regional interdependence of markets in general.

## 5. Empirical Results

### 5.1 A graphical portrayal.

To depict graphically the evolution of relations among stock markets, we make calculations within overlapping windows of pre-specified length. Each window excludes the first daily observation from the previous window and adds one more daily observation in sequence. Hence successive values of the statistics are analogous to moving averages.

For regional (geometric) averages of covariance, correlation, and volatility, ( $\gamma_{cov}$ ,  $\gamma_{corr}$ , and  $\gamma_{\sigma^2}$ ), a six-month window gives the values plotted in Figures 1-3. The spike in  $\gamma_{cov}$  for the East Asian countries in Figure 2 coincides with the Asian crisis and appears to represent a significant break from the past. Before the crisis, Asia had a slightly lower covariance than Europe on average, but this was reversed dramatically during the crisis. Around the middle of

the crisis period,  $\gamma_{\text{cov}}$  fell substantially in Asia, though it remained at a level much higher than the pre-crisis period and considerably higher than in Europe.

The European countries too display an increase in covariance during the crisis period. The largest part of the rise in Europe came later and was less pronounced than in Asia. Unlike Asia, no mid-crisis period downturn is visible in Europe; there is a sharp second upward movement instead.

Did correlations within the two regions move as much or can some part of the spikes in covariance be explained by higher volatility? Figure 3 and 3 present visual evidence about this question. Figure 3 shows a secular increase in correlation among European countries which appears to begin up to a year before the crisis. During the crisis, European and Asian countries displayed concurrent upward trends in correlation. Asia's trend was sharper near the beginning of the crisis but it leveled off and began to turn down in late 1998 while Europe's continued upward after a temporary dip in late April of 1998<sup>3</sup>.

Figure 4 plots average volatility. The similarity of the pattern to covariance (Figure 2) is obvious even visually. Prior to the crisis, volatility was slightly higher in Asia than in Europe. The gap widened substantially as the crisis deepened and then narrowed toward the end of 1998.

The Jennrich  $\chi^2$  statistic, measuring the stability of the correlation matrix, is computed in a different fashion. Here one-year overlapping windows are each divided into two six-month sub-periods; the statistic compares correlation matrices between the sub-periods. Hence, each one-year window yields one value of the Jennrich  $\chi^2$ . Successive windows drop the first day from the previous window and add the day after the previous last day. Figure 5 plots the p-value from the Jennrich test of the hypothesis that the two adjacent six-month periods have the same correlation matrix, so values near zero imply a strong likelihood that the matrix has changed.

For both Europe and Asia during the pre-crisis period, there are many large p-values; i.e., little evidence of an evolving correlation matrix. There are some near zero but then this statistic like any other has unavoidable sampling variation. The striking feature of Figure 5 is that Asia's

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<sup>3</sup> Because of the rolling window, there is considerable dependence across time in these plotted numbers. For instance, the dip in European correlation in the last few days of April 1998 was probably induced by dropping a few observations from the window. These same observations induced the sharp rise in the computed average correlation around late October 1997, six months earlier.

p-value falls essentially to zero during the crisis and remains there throughout<sup>4</sup>. The Jennrich  $\chi^2$  p-value is also relatively low for Europe during the crisis period, but not persistently as low as for Asia.

Figure 6 depicts the evolution of the sample curvatures of efficient frontiers within the Europe and Asia regions before and during the 1997 crisis. Each point gives the curvature of a sample efficient frontier constructed from daily return data for six months ending on the plotted date. Higher curvature implies less effective diversification within the region.

For about 18 months prior to the crisis and for six months into the crisis, Asia's curvature was lower than Europe's. This no doubt reflects the similarity among European economies and the concomitant smaller potential for diversification. By early 1998, however, Asia's curvature had increased dramatically and exceeded Europe's by a sizeable margin. By this time at least six months of the crisis period fell within the window's calculation. Perhaps surprising, late 1998 saw a sharp reduction in Asia's curvature followed by an even sharper increase in curvature for Europe. This is consistent, of course, with the relative movements of the average covariances in the two regions (Figure 2) around the same time.

## 5.2 Statistical Tests

The pictures discussed above seem to portray remarkable changes within Asia during the 1997 crisis and less dramatic but still noticeable changes in Europe. But in dealing with statistics, a picture's purported value of a thousand words means very little; indeed, the intra-ocular tests given by a picture can often be misleading. To be assured of reliable inferences, one is obliged to adopt more formal methods.

### 5.2.1. Volatility Spillover

Table 2 reports tests for the presence of volatility spillover effects before and during the crisis in both regions. The first hypothesis, (2), that volatility spillover was present in pre-crisis and crisis periods and had the same intensity in both, is not supported by the evidence in either region. Neither p-value is even close to significant.

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<sup>4</sup> The plot stops in mid-1998 because the Jennrich statistic requires a six-month sample before and after the plotted date.

In contrast, there is strong evidence of spillover in Asia during the crisis, a p-value of .00046 rejecting hypothesis (3). There is weak evidence, (p-value .088) that volatility spillover occurred also in Europe.

Whatever the underlying causes of Asia's crisis might have been, they apparently induced a structural change in the propensity of Asian countries to import recent volatility disturbances from their neighbors. Remember that (1) measures very short-term contagion, volatility that appeared in neighboring countries just a few days earlier (i.e., in the previous week.) In the pre-crisis period, there was no evidence at all of such contagion. It would be interesting to know whether such a marked increase in contagion is a general feature of crises.

### ***5.2.2 Variability, Co-movement, and Efficient Frontier Curvature***

Regional geometric averages of covariances, correlations, volatilities, and efficient frontier curvature would have complicated sampling distributions even if returns were Gaussian. We admit to utter ignorance about the forms of these distributions. This is all the more problematic because kurtosis statistics (Table 1) show the departure from Gaussian typical of asset returns. Hence, it is not only prudent but absolutely essential to construct sampling distributions by re-sampling from the original data; i.e., by employing the “bootstrap.”<sup>5</sup>

Our resampling plan adheres faithfully in every instance to the procedures actually used in computing the sample point estimate from the data. To give a concrete example, suppose we wish to test whether covariances within a region, say Asia, increased from the pre-crisis to the crisis period. The point estimate would simply be the difference between the geometric averages for the Asian region in the two periods; i.e.,  $\gamma_{\text{cov,Asia,Crisis}} - \gamma_{\text{cov,Asia,Pre-Crisis}}$ . The first of these averages is calculated from 913 observations while the second is based on 392 observations, those being the numbers of daily returns available in the two sub-periods.

Resampling for this statistic thus involves first selecting 913 calendar dates at random (with replacement) along with the actual daily returns for the eight Asian countries on those dates. Next, a second random selection of 392 calendar dates and their corresponding returns are selected. Covariances among the eight countries are computed for the two samples separately. Their geometric averages are then differenced to produce  $\gamma_{\text{cov,Asia,Sample\#2}} - \gamma_{\text{cov,Asia,Sample\#1}}$ . The

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<sup>5</sup> A basic reference on the bootstrap is Efron [1982].

random selections are repeated 10,000 times, thereby generating a sampling distribution for 10,000 geometric mean covariance differences. Statistical significance is gauged by the position of the actual data statistic within the fractiles of the resampled distribution. Figure 7 plots the bootstrapped sampling distribution<sup>6</sup> for this illustrated example, (pre-crisis to crisis geometric mean covariance difference for Asia.) The point estimate (3.63) lies completely outside the sampling distribution and is thus statistically significant.

A similar but distinct method is used to develop a resampling distribution for testing across regions. For example, we might like to know whether Asia and Europe had statistically different covariances within the crisis period. The point estimate is  $\gamma_{\text{cov,Asia,Crisis}} - \gamma_{\text{cov,Europe,Crisis}}$ . In this case, a pair of countries is selected at random from the sixteen available and their covariance is computed from the 391 crisis period observations. The pairwise selection is repeated (with replacement) to obtain 56 resampled covariances, a number ordained by the fact that each region of eight countries has  $8(7)/2=28$  distinct **true** covariances. The 56 resampled covariances are then divided into two groups, the geometric mean is computed within each group and their difference,  $\gamma_{\text{cov,Group\#1,Crisis}} - \gamma_{\text{cov,Group\#2,Crisis}}$ , is taken. Repeating this operation 10,000 times provides the sampling distribution required.

For inter-regional comparison of efficient frontier curvature for a given period, a slight modification is required. If the same country were selected twice in a bootstrap pseudo-region, the covariance matrix would be singular by construction, thus implying infinite curvature. Consequently, eight different countries must be selected at random. Efficient frontier curvature is computed using the covariance matrix of those eight and compared with the corresponding curvature for the eight countries not selected. The difference in the two curvatures, tabulated 10,000 times, provides the bootstrap resampled distribution.

Table 3 reports all the results. The two left columns provide evidence on the differences between the crisis and pre-crisis periods for each region considered separately. The two right columns given comparisons between the Asian and European regions by sub-period.

There are strong indications that covariances, correlations, and volatilities increased during the crisis in both regions. All the p-values are .0000, thus firmly rejecting the hypotheses

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<sup>6</sup> The bootstrapped data are fit with a non-parametric density estimator using the Gaussian kernel and a band width determined by the normal reference rule. See Scott [1992], chapter 6.

that these parameters remained constant over time. Prior to the crisis, covariances were not significantly different in Europe and Asia but they became significantly higher in Asia during the crisis. Correlations were significantly higher in Europe in both periods. Volatility was significantly higher in Asia in both periods though the magnitude of the difference and its level of significance increased during the crisis<sup>7</sup>.

The  $\eta$  statistic, which measures the relative contribution of correlation to the change in covariance between periods, (see (5)), is significant at better than the 1% level in both regions, thus revealing that correlation change was more important than volatility change in explaining the increases in observed covariances from pre-crisis to crisis.

Efficient frontier curvature increased significantly in Asia (p-value .0348) during the crisis, which confirms that diversification opportunities declined substantially. In Europe, the efficient frontier's curvature also increased during the crisis period but only moderately and with just a marginally significant p-value of .0839. As measured by curvature, diversification was actually better in Asia than in Europe before the crisis, though the difference was not statistically significant. Diversification's drastic fall in Asia during the crisis reversed the difference, which then became significant (p-value .0093.)<sup>8</sup>

The impressive decline in diversification potential in Asia at the time of the crisis is consistent with rational investors driving down asset values. Of course there is no way to ascertain whether a reduction in diversification actually caused the crisis or even whether it was an effect rather than a cause. Nonetheless, it appears to be an interesting smoking gun.

## 6. Conclusions and Future Research

The 1997 Asian "crisis" brought staggering declines in equity values and exchange rates, which other regions escaped. Though painful to Asian investors, this episode provides an

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<sup>7</sup> A recent paper by Forbes and Rigobon [1999] suggests that observed increases in correlations should be interpreted with caution. They argue that "...when stock market volatility increases, standard estimates of cross-market correlations will be biased upward." In the appendix to this paper, we present a counter-argument which concludes that no such bias is actually present in our sample.

<sup>8</sup> The reader may wonder why the Asia-Europe curvature difference of  $-65.1$  was not significant pre-crisis while the  $+89.5$  crisis difference was highly significant even though it is not all that much larger in absolute value. This seeming puzzle is explained by differences between the bootstrapped resampling distributions. The pre-crisis period had more than twice as many observations (913 vs. 392) and the efficient frontier curvature's sample volatility increases with sample size. Intuitively this phenomenon must be related to higher apparent (as opposed to true) diversification potential in smaller samples; i.e., mean curvature also increases with sample size, *ceteris paribus*.

opportunity for analysis and study. Perhaps we can learn something about precipitating factors in financial debacles and uncover ways to mitigate or even avoid them. Here, we offer a clinical comparison of the diseased patient, Asia, and a healthy patient represented by Europe. Our focus is on volatility spillover and diversification potential within each region. The basic idea is to examine and compare the two patients' financial fluids in an effort to understand the ailment.

To aid in this diagnostic endeavor, we design and apply some new statistical equipment to succinctly measure patterns of return co-movement and volatility within a region. These include general measures of covariance, correlation, volatility, and diversification potential.

In the three-and-a-half years prior to the crisis, Asian countries as a group had slightly higher volatility but somewhat lower correlation than their European counterparts. The general level of covariance was roughly the same in the two regions. There was no evidence of volatility spillover; i.e., return shocks in were not propagated from a country to its neighbors in either region.

An increased level of return volatility and co-movement accompanied the onset of the crisis. Both Asia and Europe experience statistically significant increases in covariance, correlation, and variance. Correlation actually increased somewhat more in Europe than in Asia<sup>9</sup>, but this was swamped by much larger increases in covariance and in volatility in Asia. The volatility and covariance increases were both almost four times larger in Asia. This was exacerbated by the sudden appearance of volatility spillover, highly statistically significant in the case of Asia.

Diversification potential, as measured (inversely) by the curvature of the sample efficient frontier, tells a compelling story. Before the crisis, diversification was actually more potent within the Asian region, due perhaps to closer ties among countries within the European community than among the more diverse Asian economies. During the crisis this situation was reversed. Asian diversification potential became much worse. Its change from the pre-crisis to the crisis period was statistically significant and it fell behind Europe's diversification potential by a statistically significant margin. A large loss in diversification potency reduces the overall benefit of investing. That alone has the potential to precipitate sizable declines in asset values

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<sup>9</sup> However the relative increase in correlation was higher in Asia since it was considerably lower in the pre-crisis period. Within each region, correlation was responsible for more of the covariance increase than was volatility; (This is measured by our  $\eta$  statistic, defined in equation 5 of the text.)

though obviously we cannot know whether the observed change was a cause or an effect of the crisis.

A better understanding of regional interdependence will require something beyond stock returns. Capital movement and event studies of major crisis incidents would be informative. A better understanding of the seeming link between stock market movements and currency devaluations is also crucial. But no one is quite sure yet just how and why currency changes impact stock returns and vice versa. It would also be interesting to ponder theoretical reasons for the empirical findings in our clinical investigation.

The test statistics and procedures introduced here can be used unmodified in the study of industry linkages – to ascertain how industry or sectoral indices relate to one another and how that relation evolves over time. They could be applied with equal ease to study the relations among different stock exchanges within a country. They could measure the impact of legislation, policy change, or a technological innovation on the relations among industries within a country or the consequences of changes in exchange trading rules on the relations among co-existing stock exchanges.

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## Appendix

### Higher Correlation in More Volatile Times: Bias or Fact?

Forbes and Rigobon [1999] (FB) argue that increased correlation during more volatile periods could be an artifact. They derive a “bias” in the correlation coefficient and apply an adjustment for the bias to three episodes, the 1987 crash in the U.S., the 1994 Mexican peso collapse, and the 1997 Asian crisis. Since the adjustment is strictly toward zero, they derive smaller correlations in all instances and thereafter find little evidence that these crises were characterized by “contagion,” i.e., by higher positive inter-market correlations.

An appendix to their paper entitled “Proof of the Bias in the Unadjusted Correlation Coefficient” contains everything necessary to understand their argument. Adopting their notation, the true structural model is assumed to be

$$y_t = \alpha + \beta x_t + \varepsilon_t$$

where the disturbance  $\varepsilon$  has standard spherical properties and is uncorrelated with  $x$  and  $\beta \neq 0$ .

Now suppose we have two groups of observations, one with higher  $x$  volatility than the other. FB show, (though it’s rather obvious) that when the volatility of  $x$  increases while the volatility of  $\varepsilon$  remains the same, the correlation between  $x$  and  $y$  must increase.

It is crucial to understand a point not mentioned by FB. The two “groups” with differing  $x$  volatility could be (a) two different regimes during which  $x$  has disparate true volatility or (b) two sets of observations sorted by observed sample volatility. A bias exists only in the latter case.

In the former case (a), an increase in the volatility of  $x$ , *ceteris paribus*, obviously increases the true R-square of the structural model and raises the absolute value of the correlation between  $x$  and  $y$ ; (the sign of the correlation depends, of course, on  $\beta$ .) In such a circumstance, higher volatility of  $x$  would be associated correctly with higher volatility of  $y$  and higher correlation between  $x$  and  $y$ . On the other hand, if the true volatility of  $\varepsilon$  increased while  $x$ ’s volatility remained unchanged, the correlation between  $x$  and  $y$  would decrease even though the volatility of  $y$  would increase.

The above structural model specialized to a group of markets can be written as

$$r_{j,t} = \alpha_j + \beta_j f_t + \xi_{j,t}$$

where the subscript  $j$  indexes the country,  $r$  is a return, and  $f$  is some underlying driving factor. Clearly, the general level of volatility (in the  $r$ ’s) could increase during a crisis because  $f$ ’s volatility increases or because the volatilities of the  $\xi_j$ ’s increase, or both. Correlation among the  $r$ ’s would increase if the root cause were  $f$  but it would decrease if the cause were  $\xi$ . This implies that there is no necessary connection between a general increase in volatility during a

crisis and an increase in correlation. The fact that both volatilities and correlations seem to increase during most crises is merely consistent with the root cause being a rise in  $f$  volatility relative to  $\xi$  volatility.

FB seem to have in mind case (b) where both  $f$  and  $\xi$  have constant true volatilities but data miners have picked out a sub-sample of abnormally volatile  $f$ 's. Since the true correlation is constant in this scenario, the correlation coefficient estimated from the sub-sample really is biased away from zero.

The basic issue, then, is whether crises have been identified because volatility just happened to be larger than usual. The crises studied by FB were characterized most obviously by dramatic declines in asset values. But a negative average return is a phenomenon related to the mean of the distribution, not necessarily to the variance. The increase in volatility after the onset of these crises was a fact discovered later, after they had already become infamous episodes. We do not, therefore, think that any adjustment is necessary and, indeed, that such an adjustment would inappropriately bias estimated correlations downward from their true values.

**Table 1. Descriptive Statistics, Country Returns by Sub-Period**

Daily country index returns (%/day) are denominated in US dollars and tabulated for the pre-crisis period, December 31, 1993 through July 1, 1997, (913 observations), and the Asian crisis period, July 2, 1997 through December 31, 1998, (392 observations.)

	HongKong	Indonesia	Korea	Malaysia	Philippines	Singapore	Taiwan	Thailand
	Pre-Crisis							
Mean	0.0240%	0.0189%	-0.0291%	-0.0149%	-0.0006%	-0.0152%	0.0375%	-0.1133%
Standard Deviation	1.3003%	1.0190%	1.2513%	1.3010%	1.1475%	0.8777%	1.5531%	1.6187%
Kurtosis	3.882	3.919	1.282	8.243	2.334	4.951	3.471	2.659
Skewness	-0.514	-0.144	-0.022	0.103	-0.242	-0.233	-0.168	-0.085
Minimum	-7.72%	-5.28%	-6.03%	-7.48%	-6.20%	-5.24%	-7.39%	-7.80%
Maximum	5.63%	6.47%	6.04%	9.97%	4.80%	5.52%	6.62%	6.45%
	Crisis							
Mean	-0.1319%	-0.4242%	-0.1118%	-0.2756%	-0.1981%	-0.1095%	-0.1244%	-0.1994%
Standard Deviation	2.7300%	6.4720%	4.4184%	4.0963%	2.8091%	2.2490%	1.9586%	3.5978%
Kurtosis	5.908	7.942	3.938	6.655	1.650	3.234	2.078	2.379
Skewness	0.437	-0.947	0.044	0.611	0.117	0.348	-0.131	0.764
Minimum	-13.63%	-42.84%	-19.18%	-22.04%	-10.24%	-9.59%	-8.98%	-9.38%
Maximum	15.37%	21.48%	20.12%	22.20%	11.56%	9.94%	6.72%	17.44%

**Table 1, (continued). Descriptive Statistics, Country Returns by Sub-Period**

	France	Germany	Italy	Netherlands	Portugal	Spain	Switzerland	UK
	Pre-Crisis							
Mean	0.0252%	0.0432%	0.0357%	0.0730%	0.0586%	0.0647%	0.0643%	0.0421%
Standard Deviation	0.8509%	0.8357%	1.3396%	0.7257%	0.7833%	0.9208%	0.8361%	0.6511%
Kurtosis	1.150	1.046	1.431	1.761	4.213	1.716	1.488	0.756
Skewness	-0.135	-0.341	0.028	-0.343	-0.175	-0.399	-0.080	-0.256
Minimum	-3.71%	-3.71%	-5.68%	-4.02%	-5.20%	-5.36%	-3.31%	-2.97%
Maximum	3.09%	2.64%	6.02%	2.43%	3.75%	3.12%	3.55%	2.26%
	Crisis							
Mean	0.0936%	0.0636%	0.1544%	0.0639%	0.0903%	0.0999%	0.0767%	0.0532%
Standard Deviation	1.2811%	1.4600%	1.7452%	1.4338%	1.4828%	1.5641%	1.3189%	1.0438%
Kurtosis	1.923	1.239	1.176	1.090	2.912	2.396	1.810	1.028
Skewness	-0.030	-0.371	-0.211	0.061	-0.417	-0.255	0.082	-0.034
Minimum	-4.74%	-5.55%	-6.40%	-4.89%	-6.72%	-6.02%	-4.09%	-3.14%
Maximum	5.61%	4.94%	6.69%	5.31%	5.84%	7.16%	6.66%	3.84%

**Table 2. Tests for Volatility Spillover**

For each of two regions, Asia and Europe, a system of eight simultaneous equations is estimated using US\$-denominated country index daily returns. There is one equation per country in the form  $\Delta\sigma_{i,t} = \alpha_i + \sum_{j \neq i} [\beta_{i,j}\Delta\sigma_{j,t-1} + \Delta\beta_{i,j}\delta_t\Delta\sigma_{j,t-1}] + \varepsilon_{i,t}$  where  $\sigma_{i,t}$  is the estimated volatility computed from daily returns during week t in country i,  $\Delta\sigma_{i,t} = (\sigma_{i,t} - \sigma_{i,t-1})$  is the weekly first difference,  $\delta_t$  is an indicator variable which is zero in the pre-crisis period and unity during the crisis period, and  $\varepsilon_{i,t}$  is a disturbance not necessarily independent across equations (countries.) Joint tests that all  $\beta_{i,j}$ 's are zero would be rejected if there is evidence of volatility spillover in both the pre-crisis and crisis periods of the same intensity. Joint tests that all  $\Delta\beta_{i,j}$ 's are zero would be rejected if volatility spillover changed (and was statistically more significant) during the crisis period. The sixteen countries are listed in Table 1. There are 258 weekly observations. To save space, the estimated coefficients and other statistics are not reported but will be provided to interested readers upon request.

	Asia	Europe
Null Hypothesis	p-value	
$\beta_{i,j} = 0, (j \neq i, \forall i)$	0.355	0.642
$\Delta\beta_{i,j} = 0, (j \neq i, \forall i)$	0.0046	0.0856

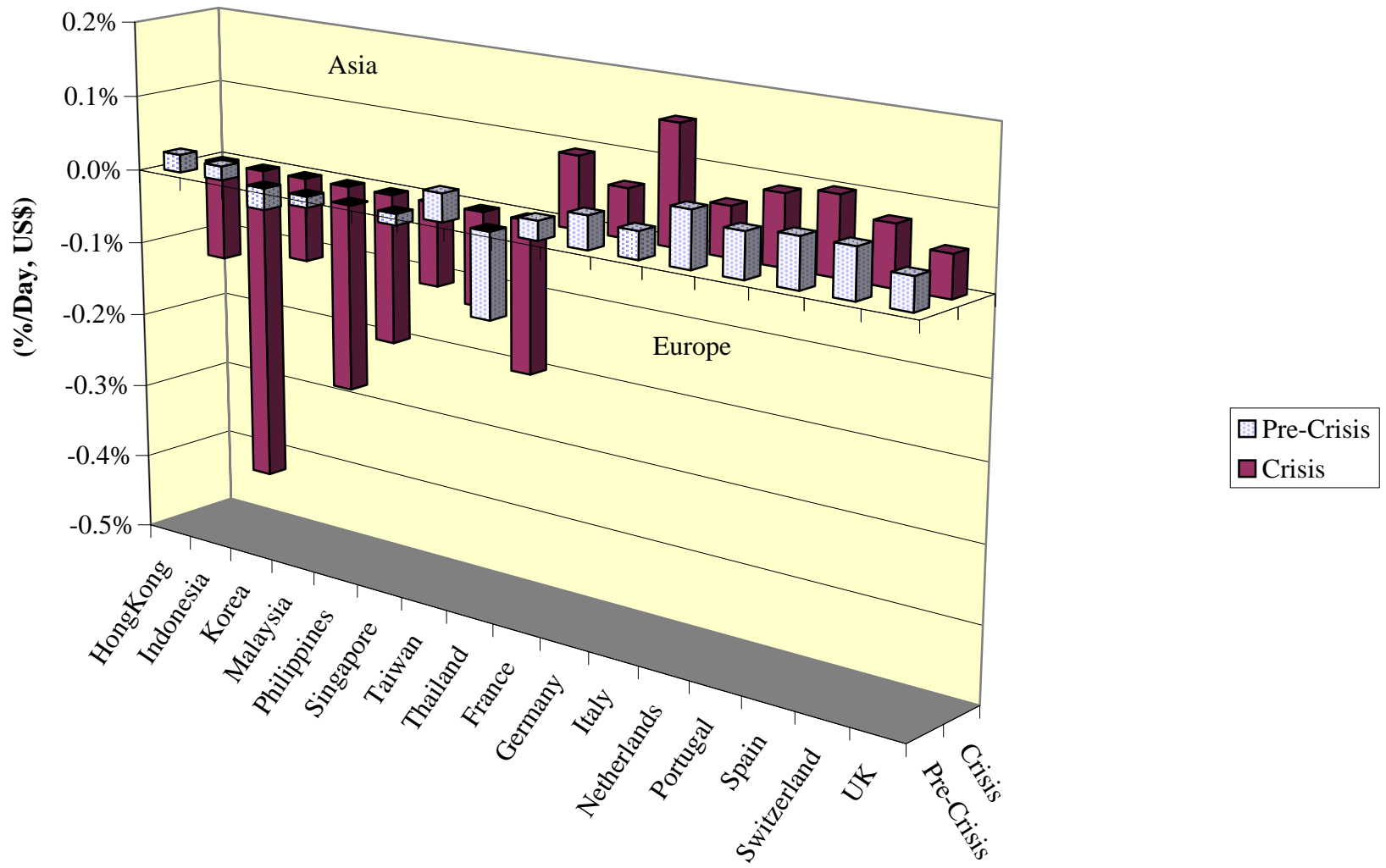
**Table 3. Comparisons Across Periods and Regions of Diversification Potential**

Geometric averages of covariances, correlations, and volatilities are calculated from US\$-denominated daily index returns for eight Asian and eight European countries before and during the 1997 Asian crisis. Efficient frontier curvatures are calculated for the countries within each region. The  $\eta$  statistic measures the relative importance of correlation to an observed change in covariance. The pre-crisis period was December 31, 1993 through July 1, 1997. The crisis period was July 2, 1997 through December 32, 1998. Changes in the statistics across the two periods and differences in the statistics across regions within each period are tabulated and compared against resampled (bootstrapped) probability distributions. The p-values (in parentheses) indicates the fractile of the bootstrapped distribution corresponding to the observed point estimate.

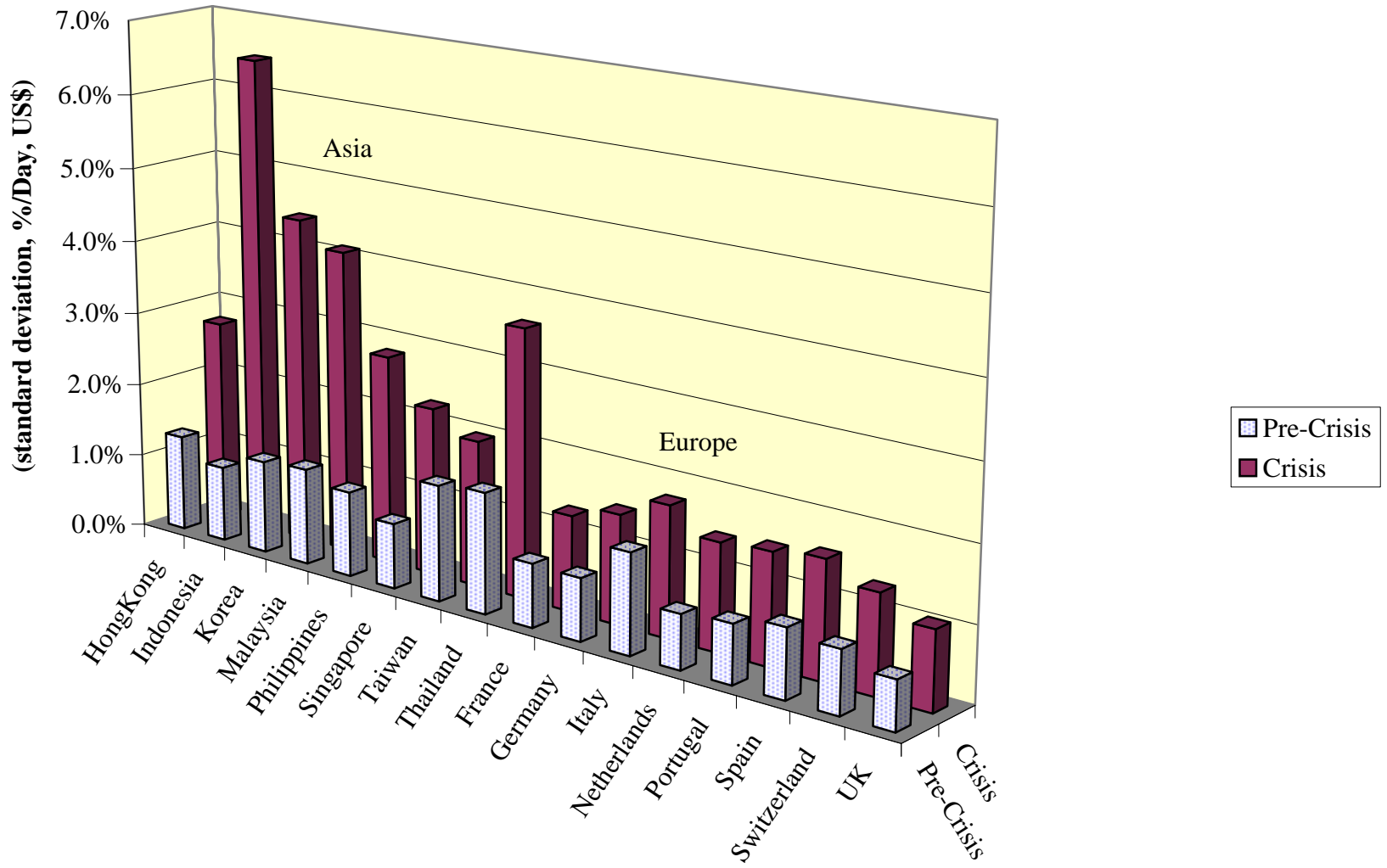
Crisis – Pre-Crisis		Asia - Europe	
Covariance <sup>10</sup>			
Asia	3.63 (.0000)	Pre-Crisis	-.0648 (.7869)
Europe	1.08 (.0000)	Crisis	2.48 (.0055)
Correlation			
Asia	0.206 (.0000)	Pre-Crisis	-0.251 (.9928)
Europe	0.298 (.0000)	Crisis	-0.343 (.9952)
Standard Deviation (%/day)			
Asia	2.069% (.0000)	Pre-Crisis	0.387% (.0030)
Europe	0.553% (.0000)	Crisis	1.903% (.0016)
Efficient Frontier Curvature			
Asia	160. (.0309)	Pre-Crisis	-65.1 (.6710)
Europe	5.27 (.1744)	Crisis	89.5 (.0093)
$\eta$ statistic			
Asia	0.309 (.1578)		
Europe	0.359 (.3947)		

<sup>10</sup> Covariances have been scaled upward by a multiple of 10<sup>4</sup>.

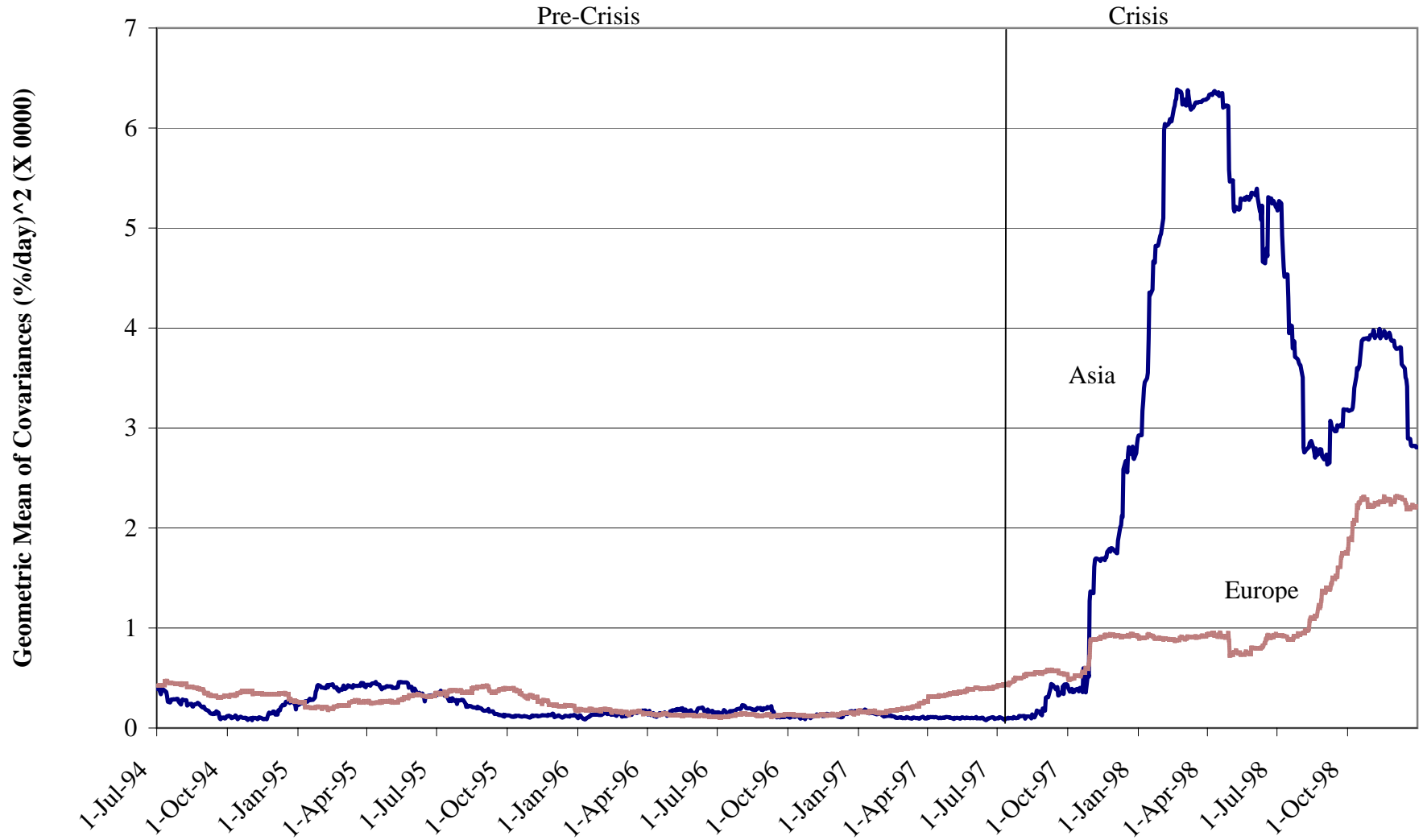
**Figure 1, Panel A. Mean Returns by Region and Period**



**Figure 1, Panel B. Volatility by Region and Period**



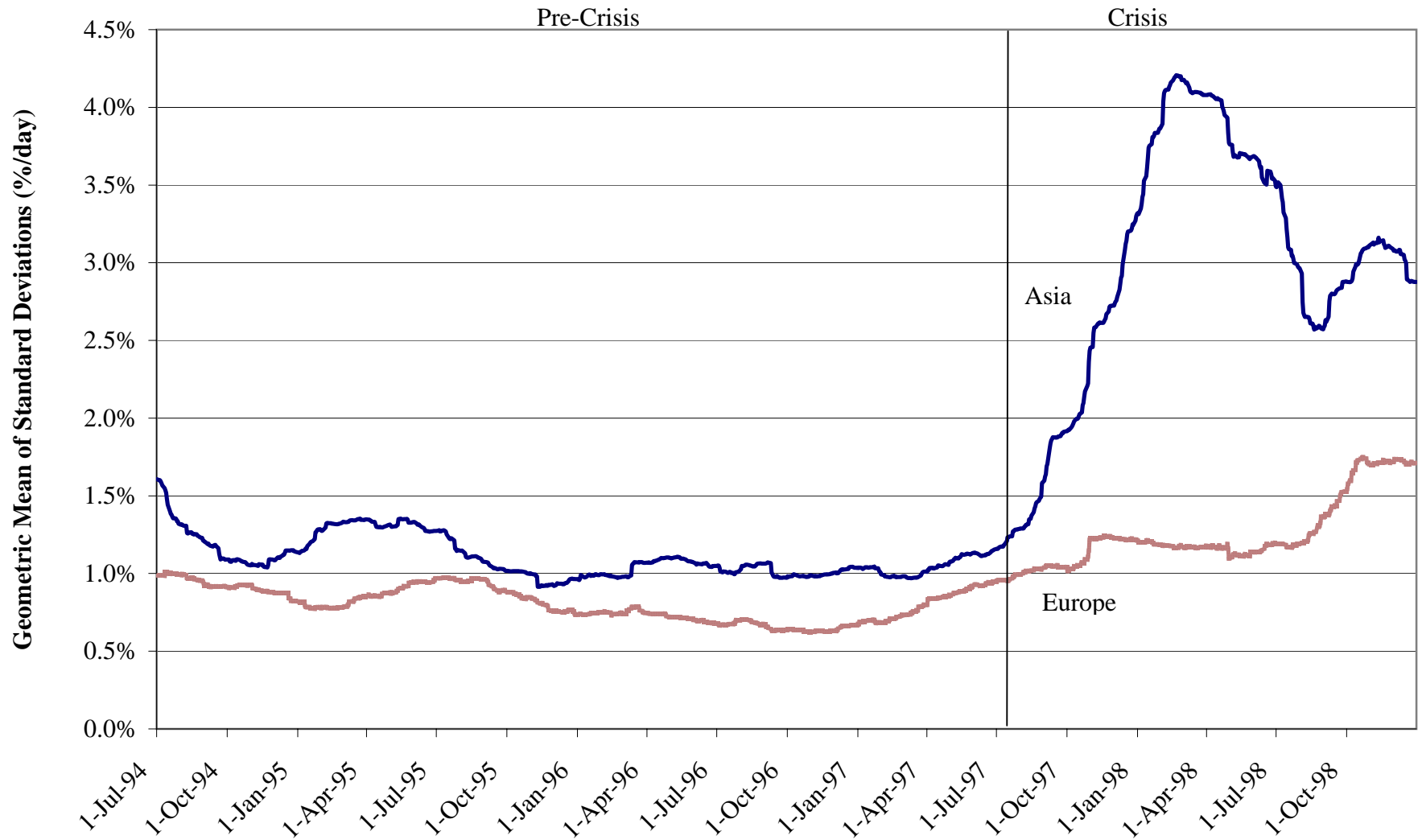
**Figure 2. Regional Average Covariance**



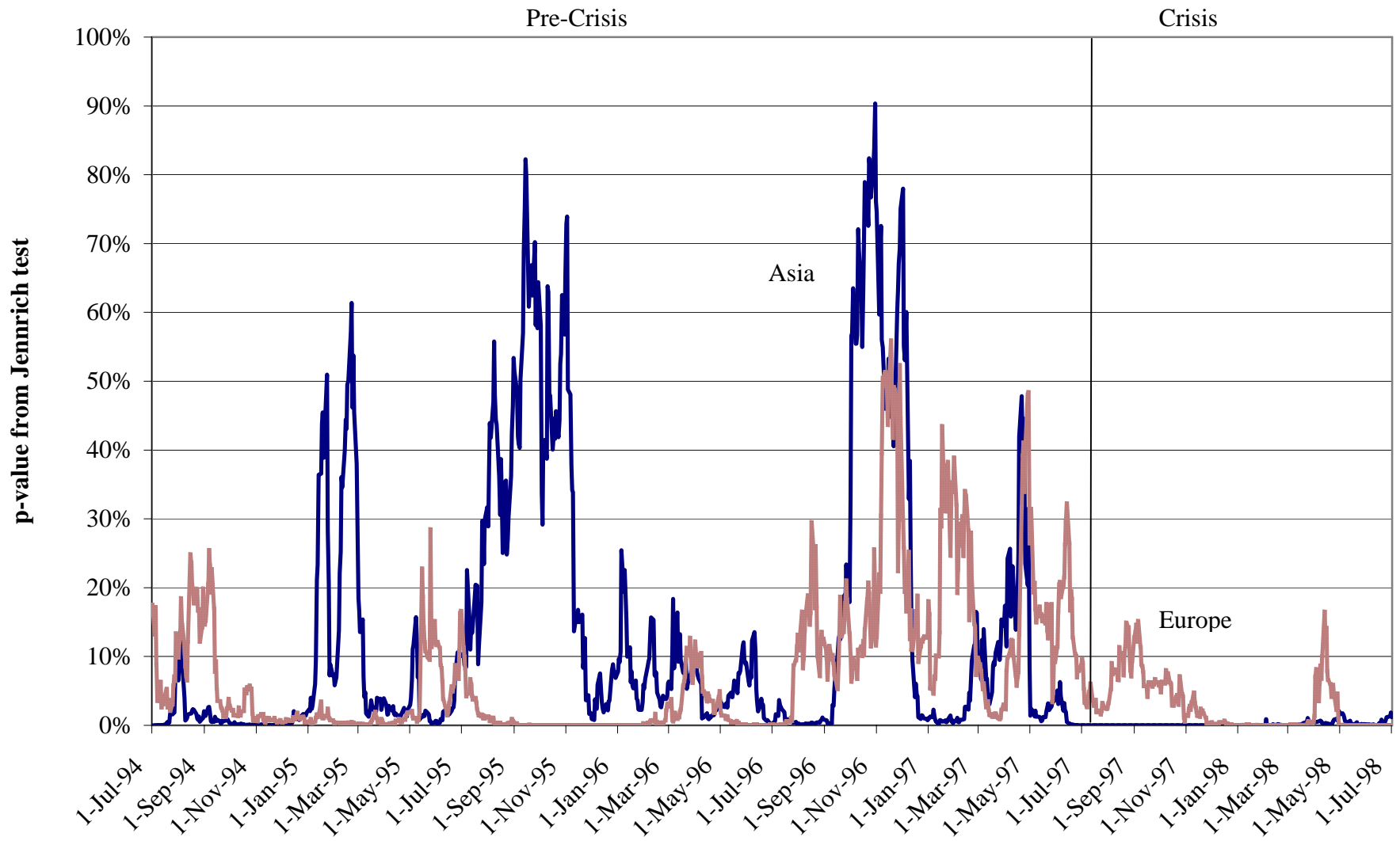
**Figure 3. Regional Average Correlation**



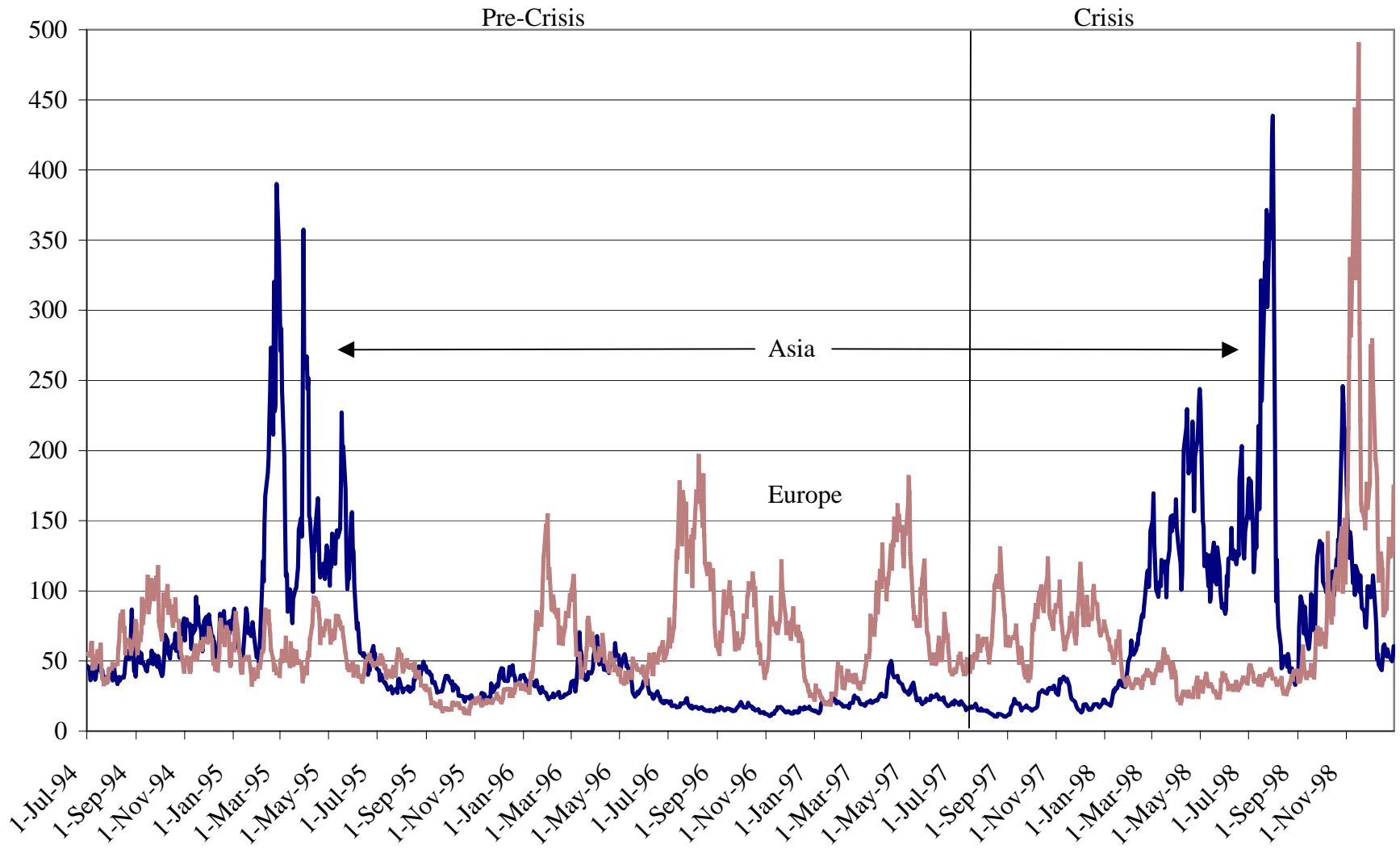
**Figure 4. Regional Average Volatility**



**Figure 5. Jennrich test of equality in Successive Correlation Matrices**



**Figure 6. Curvature of Regional Sample Efficient Frontiers**



**Figure 7. Non-Parametric Estimated Density for Change in Covariance  
from Pre-Crisis to Crisis Period, Asia**

