No. 1056

Intra and Inter-Regional Causal Linkages of Emerging Stock Markets: Evidence from Asia and Latin America in and out of Crises

by

Eiji Fujii

August 2003

No. 1056

Intra and Inter-Regional Causal Linkages of Emerging Stock Markets: Evidence from Asia and Latin America in and out of Crises

by

Eiji Fujii

Intra and Inter-Regional Causal Linkages of Emerging Stock Markets: Evidence from Asia and Latin America in and out of Crises

Eiji Fujii
Institute of Policy and Planning Sciences
University of Tsukuba

Abstract

This study examines the causal linkages among several emerging stock markets in Asia and Latin America since 1990. These markets experienced both rapid growth and major upheaval during the sample period, and thus, provide potentially rich information on the nature of cross-market interactions. Using daily observations of stock indices and the GARCH family of econometric models, we conduct the residual cross-correlation function tests to investigate cross-market causality both in the first and second moments of the stock returns. The empirical results reveal significant causal linkages both within each region and across the two regions. Further, our rolling test results indicate that the significance of the causality varies considerably over time. Importantly, we find that the causal linkages tend to strengthen particularly at the time of major financial crises. The empirical results also point to some imperative issues including inter-regional asymmetry in the causality and persistence of shocks on market linkages.

JEL Classification: F30, G15
Keywords: causality; contagion; GARCH; volatility spillover; stock markets

Acknowledgements: I am grateful to Yin-Wong Cheung for helpful comments and suggestions.
Address for Correspondence: Eiji Fujii, Department of Economics, Institute of Policy and Planning Sciences, University of Tsukuba, Tennodai 1-1-1, Tsukuba, Ibaraki 305-8573, Japan. Phone/Fax: +81 29 853 5176. E-mail: efujii@sk.tsukuba.ac.jp.

1. Introduction

A series of financial crises in the past decade have generated a heated policy debate over desirability of swift financial liberalization for emerging markets (Furman and Stiglitz, 1998; Radelet and Sachs, 1998). Among the cornerstone issues is "contagion" of financial crises across countries. If the sequence of financial turmoil in numerous countries is a result of systematic deterioration of their own fundamentals, then it is primarily their domestic macroeconomic policy conducts, rather than the financial liberalization, that needs to be addressed. On the other hand, if the emerging economies are inherently vulnerable to negative effects of financial instability occurring elsewhere, then it may well be justified to actively tame some of the financial flow into and/or out of the markets. The crucial issue has motivated numerous recent studies (Baig and Goldfajn, 1999; Edwards and Susmel, 2001; Forbes and Rigobon, 2002) to empirically examine whether or not the cross-country interactions of financial markets during crisis periods are significantly different from those in stable times. Some studies (Baig and Goldfajn, 1999; Calvo and Reinhart, 1996) find that financial market correlations across countries increase significantly during crises, rendering support to the view that crises are contagious. In a recent study, however, Forbes and Rigobon (2002) casts a serious doubt on the contagion hypothesis by demonstrating that the previous empirical evidence based on market correlations are prone to a bias resulting from neglecting heteroskedasticity in the financial time series. Since the accumulated evidence has yet to reach a definitive conclusion, gaining further insight into the issue is warranted.

In this study, we investigate the causal linkages among the stock markets of several emerging economies in Asia and Latin America since 1990. These markets have experienced both rapid growth and major upheaval over the past decade, and thus, provide potentially rich information on the nature of the cross-market interactions in altering market environments.[1] In particular, we are interested in finding out if inter-market relationships vary significantly as the markets go into and out of financial crises. Using daily observations of stock indices of several Asian and Latin American markets and the generalized autoregressive conditional heteroskedasticity (GARCH) family of econometric models, this study conducts the residual cross-correlation function (CCF) tests developed by Cheung and Ng (1996) to investigate cross-market causality both in the first and second moments of stock returns within and across the regions. By implementing the CCF tests with a rolling window, we illustrate how the significance of the inter-market causal linkages has evolved over the past decade as the markets experienced periods of stability and volatility.

Our empirical methodology provides several important advantages over the standard correlation analyses performed by numerous preceding studies. First, by modeling the stock return dynamics as autoregressive (AR) processes with the GARCH feature, we explicitly account for conditional volatility present in the time series data. The CCF tests are conducted on the (squared) *standardized* residuals obtained from the estimated AR-GARCH models, and thus, the results are not distorted by heteroskedasticity present in the raw data.[2] Second, cross-correlations of the standardized residuals and their squares will be examined at various lags and leads to

---

[1] Our sample period contains numerous incidents of currency and/or banking crises. They include the currency crises in Argentina and Brazil in 1990-91, the twin crises in Mexico and the subsequent disorder in Brazil and Argentina in 1994-95, the 1997-98 Asian crisis, and the Brazilian currency crisis in 1999. For a summary and chronology of these and other crisis incidents, see Goldstein, Kaminsky, and Reinhart (2000).

[2] It is noted that, as shown in the empirical results, the standardized residuals are not serially correlated or conditionally heteroskedastic.

investigate synchronous and non-synchronous market interactions both in the first and second moments of stock returns. Testing for causality in variance, in addition to that in mean, provides extra information to illuminate how the markets interact in volatile environments. Also, the direction of causality and the lag structure offers valuable information for understanding the information flow between markets. Third, by investigating market linkages through a rolling window, we show how the inter-market relationships have evolved over time as the Asian and Latin American markets go in and out of financial crises. Numerous previous studies examine difference in market correlations between two particular samples that are pre-selected as stable and volatile periods, respectively. Our rolling CCF tests, on the other hand, illustrate how the significance of inter-market relationships has varied through the entire 1990-2001 sample. Finally, by using data on four Asian and four Latin American markets, we investigate both intra-regional and inter-regional causal nexuses. As a result, we are able to provide some information on the relevance of regional boundaries for market contagion.

The linkages between national stock markets have been a significant research issue. In particular, comovement of the major world markets such as New York, London, and Tokyo has been scrutinized in various ways (King and Wadhwani 1990; Hamao, Masulis, and Ng 1990; Cheung and Ng 1996).[3] There are also studies that examine changes in the market linkages over long horizons (Koch and Koch 1991; Longin and Solnik 1995). The overall evidence from the previous literature is that the major markets

[3] King and Wadhwani (1990) construct a model of market contagion due to an erroneous inference to price changes in an overseas market. Hamao, Masulis, and Ng (1990) adopt GARCH modeling techniques to document volatility spillover between the US, UK and Tokyo markets. Cheung and Ng (1996) also report volatility spillover between New York and Tokyo by applying the causality in variance test they devise. See also Kaplanis (1988), King, Sentana and Wadhwani (1994), Lee and Kim (1993), and Ramchand and Susmel (1998).

interact significantly with each other, though not necessarily symmetrically. In addition, it has been reported that the market interdependence has grown overtime.[4]

More recently, the crises in Asia and Latin America have drawn much attention to the interactive dynamics among emerging financial markets. A critical question raised in the literature is whether or not financial crises are contagious. That is, it has often been conjectured that an ill fate of one market spills over to bring down others that are otherwise healthy.[5] A number of studies address the question by examining if the market comovement under crisis circumstances is significantly different from that in quiet periods.

For instance, in investigating the pair-wise cross-country comovement of financial variables for five Asian economies, Baig and Goldfajn (1999) report that the cross-country correlations in currency and sovereign spreads significantly increase during the 1997-98 crisis. Forbes and Rigobon (2002), however, suggest that the results of the standard correlation analyses are not reliable since they do not take into account increase in volatility during turmoil. Removing the heteroskedasticity-bias from market correlations, Forbes and Rigobon (2002) find little evidence for a significant increase in market comovement during the 1994 Mexican and the 1997 Asian crises.

Edwards and Susmel (2001) pursue an alternative methodology in which they model cross-market volatility comovement as switching regimes in conditional variance processes. Using weekly stock data and the switching ARCH models, Edwards and

[4] In examining eight national stock indices for 1972, 1980, and 1987, Koch and Koch (1991) find that the growing interdependence is confined to markets within the same geographical region and within a 24-hour period. In another study using 1960-1990 data, Longin and Solnik (1995) find not only that the cross-national market conditional correlation has increased over time, but also that it tends to rise in periods of high volatility.

[5] Contagion may be defined in various ways, and there seems no unified definition in the literature. For a discussion of conceptual issues of contagion, see Masson (1998) among others.

Susmel (2001) find strong evidence of volatility spillover among Argentina, Brazil, Chile, and Mexico in the 1990s. They also report that the Latin American markets are generally independent of the influence of the Hong Kong market, suggesting that a regional boundary matters to contagion. These previous studies above have made undoubtedly important contributions to our understanding of how emerging financial markets interact with each other in alternative environments. The reported empirical evidence, however, is rather mixed, and therefore, the issue of market contagion remains unresolved.

The current study provides further empirical appraisal of the contagion hypothesis for emerging stock markets by depicting how the inter-market causal linkages have shifted over the past decade in Asia and Latin America. To anticipate the results, we find that the significance of the market linkages, both within each region and across the two regions, varies over time considerably. Importantly, the causal relationships are found to strengthen particularly at the time of major financial crises. The empirical results also point to some imperative issues such as inter-regional asymmetry in the causal relationships and persistence of shocks on market linkages.

The remainder of this study is organized as follows. Section 2 contains the data description and the results of preliminary data analysis. Section 3 describes the empirical methodology in two steps. Subsection *3.a* discusses our modeling strategy for the stock return dynamics. Subsection *3.b* describes the residual CCF tests for causality in the first and second moments of the stock returns. As a first set of empirical evidence, section 4 presents the results using the data for the entire sample of 1990-2001 period. In section 5, we explore the possibility of time-dependent stock return dynamics. Specifically, we implement the CCF tests with a rolling window so as to trace the evolution of the cross-market linkages over the twelve-year period. In view of the results, we discuss how the cross-market causal relationships have shifted in and out of financial crises. Section 6 provides concluding remarks.

2. Data and Preliminary Analysis

We examine the daily observations of the US dollar-denominated stock indices of four Asian markets: Hong Kong; Malaysia; the Philippines; and Thailand, and four Latin American markets: Argentina; Brazil; Chile; and Mexico, constructed by the Morgan Stanley Capital International (MSCI). The sample period is from January 1, 1990 to November 14, 2001.[6] The MSCI data are retrieved from the *Datastream*, and all series are converted into logarithms. Figure 1 plots the logged indices that are normalized to be unity on January 1, 1990 for comparison purposes.

Generally speaking, the Asian stock indices (Figure 1.A) were growing steadily until 1996 when the Thai market started crumbling. In the following years, all of the four Asian markets plunged as financial crises shuddered throughout the region. Although the markets also experienced downfalls in 1990 and 1994-95, the magnitude of the negative effect of the Asian crisis in 1997-98 has no comparison as Figure 1.A clearly indicates. While the Asian markets have made a decent recovery since then, the period end market indices remain below the 1990 level except for Hong Kong.

The experiences of the Latin American markets (Figure 1.B) may be characterized with recurring market crashes between fast growing phases. While the indices exhibited rather steep upward trends until 1994, the deviations from the trends

[6] We choose November 14, 2001as the end of the sample period due to the fact that some of the indices are available only up to that day, as they were discontinued and replaced by a new series thereafter.

were fairly substantial in both directions, especially for Argentina and Brazil. Among the numerous market plunges, the effects of the 1994-95 Mexican crisis and the 1997-98 Asian crisis stand particularly conspicuous for all markets.

As a preliminary step, we test all stock indices for a unit root using the efficient unit root test termed the ADF-GLS test (Elliott, Rothenberg, and Stock, 1996).[7] In accordance with the common view, we fail to reject the null hypothesis of a unit root for all level series.[8] On the other hand, the unit root hypothesis is unanimously rejected when the first difference series are tested. Therefore, we conclude that all stock indices to be I(1) series. For the remainder of this study, we examine the dynamics of the daily stock returns defined as the first difference of the logged stock indices.

Table 1 presents some descriptive statistics for the stock returns. The returns are positively skewed for Chile, the Philippines, and Thailand, and negatively so for the rest. Coupled with excess kurtosis, the null hypothesis of normality is strongly rejected by the Jarque-Bera test for all stock returns. The Ljung-Box (LB) Q-statistic indicates significant serial correlation in daily stock returns for all markets. We also calculate the LB Q-statistic for the squared returns, denoted by LB-Q^2, as a diagnosis for autoregressive conditional heteroskedasticity (ARCH) (Engle, 1982). In all cases, the LB-Q^2 statistic is highly significant, indicating strong ARCH effects. In other words, large deviations of stock returns tend to occur in a clustered fashion. These observations underline the importance of modeling both the conditional mean and the conditional

[7] It is well known that standard unit root tests, such as the augmented Dickey-Fuller (ADF) tests, possess low power against the alternative of a stationary but persistent process. The ADF-GLS test is approximately uniformly the most powerful invariant against the local alternatives.

[8] To conserve space, the unit root test results are not reported but are available upon request. Both a constant and a linear trend are included in the ADF-GLS equation when the level series are tested. For the first difference series, we include only a constant term. In evaluating statistical significance of the test statistics, we adopt the five percent level finite sample critical values tabulated by Cheung and Lai (1995).

variance processes of the stock returns jointly while allowing for serial correlations in both in order to capture their dynamics adequately.

As a general indicator of market comovement, we provide a correlation matrix of stock returns in Table 2. Apparently, the intra-regional correlations are greater than the inter-regional correlations. Within the Asian markets, the correlation ranges from 0.24 (Malaysia-Philippines) to 0.36 (Malaysia-Thailand). Similarly, for the Latin American markets, it varies from 0.23 (Argentina-Brazil) to 0.39 (Brazil-Mexico). On the other hand, the inter-regional market correlation is at most 0.17 (Hong Kong-Chile) and is as low as 0.05 (Argentina-Malaysia and Argentina-Philippines). These observations are consistent with the previous finding that market linkages are stronger within the same geographical region (Baig and Goldfajn, 1999; Edwards and Susmel, 2001; Koch and Koch, 1991).

3. Empirical Methodology

3.a Univariate Model Specifications

To capture the salient dynamics of the stock price movements summarized in the previous section, we model the daily stock returns as a stationary AR series with a time-dependent conditional variance that follows a GARCH process:

$$\begin{aligned} r_t &= \phi_0 + \phi_1 r_{t-1} + \cdots + \phi_p r_{t-p} + \varepsilon_t, \\ \varepsilon_t \mid I_{t-1} &\sim N(0, h_t), \\ h_t &= \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta h_{t-1}, \end{aligned} \tag{1}$$

where r_t is the daily stock return. Time series models with the GARCH features such as (1) are widely used as a convenient tool for modeling the dynamics of financial data that exhibit changing volatility.[9] The initial estimate of p, the order of the AR lag, in the mean equation is determined by the Schwartz-Bayesian information criteria (SBIC). For the conditional variance process, we adopt GARCH(1,1) as the basis specification. The mean and variance equations are estimated jointly by maximum likelihood. The adequacy of the model specifications is evaluated by diagnostic checking on serial correlation in the resulting standardized residuals and their squares.

3.b Residual Cross-Correlation Function Tests for Causality

In investigating causal linkages among the individual stock returns described by (1), we adopt the residual CCF tests developed by Cheung and Ng (1996). As a natural extension to the well-known Wiener-Granger causality in mean (Granger, 1969), Cheung and Ng (1996) develop a formal procedure to test for causality in the second moment between two time series. Essentially, the idea here is to extract (squared) disturbances from the univariate time series models of stock returns and inspect their cross-correlations at various lags to identify the pattern of shock and volatility transmission across markets. Testing formally for causality in variance, in addition to causality in mean, is vital for the purpose of this study since the national stock markets may interact with each other in the form of volatility spillover (Cheung and Ng, 1996; King and Wadhwani, 1990; Hamao, Masulis, and Ng, 1990). In particular, if financial crises are indeed contagious, uncertainty about one market can lead to uncertainty about others, resulting in significant volatility transmission.

We follow Cheung and Ng (1996) in briefly describing the CCF test procedures below. Let x_t and y_t be the daily returns of two different stock markets described by (1). First, we estimate (1) for x_t and y_t to obtain their respective standardized

[9] See Bollerslev, Chou, and Kroner (1992), and Campbell, Lo, and MacKinlay (1997).

residuals u_t and w_t:

$$u_t = (x_t - \hat{x}_t) / \hat{h}_{x,t}^{1/2}$$
$$w_t = (y_t - \hat{y}_t) / \hat{h}_{y,t}^{1/2} \quad (2)$$

We then calculate the sample cross-correlation between u_t and w_t at lag k, and denote it by $r_{uw}(k)$:

$$r_{uw}(k) = c_{uw}(k)(c_{uu}(0)c_{ww}(0))^{-1/2}, \quad (3)$$

where $c_{uu}(0)$ and $c_{ww}(0)$ are the sample variances of u_t and w_t, respectively, and $c_{uw}(k)$ is the k-th lag sample cross-covariance:

$$c_{uw}(k) = T^{-1}\sum(u_t - \overline{u})(w_{t-k} - \overline{w}), \quad (4)$$

with T being the number of observations. Then, the causality-in-mean test statistic is defined by:

$$S_{\mu} = T\sum_{i=j}^{k}(r_{uw}(i))^2. \quad (5)$$

Cheung and Ng (1996) show that the test statistic has an asymptotic chi-square distribution with (k–j+1) degrees of freedom for the null hypothesis of y_t not causing x_t in mean at lags from j to k, where $j \leq k$.[10] Rejecting the null hypothesis suggests that $(y_{t-k}, \ldots, y_{t-j})$ contain significant information about x_t that is not envisaged by its own model dynamics. Since the test is based on the cross-correlation of the estimated disturbances to stock returns, a rejection of the null hypothesis has a natural interpretation that there exists significant cross-market shock transmission from y_t to x_t with j to k lags.

Similarly, the null hypothesis of no causality in variance can be tested using the

[10] Causality at a specific lag q can be tested by setting $j=k=q$.

sample cross-correlation in the squared standardized residuals u_t^2 and w_t^2. The test statistic for causality in variance is defined by:

$$S_{\sigma^2} = T\sum_{i=j}^{k}(r_{u^2w^2}(i))^2, \quad (6)$$

which also has an asymptotic chi-square distribution with (k-j+1) degrees of freedom. The statistic serves to test the null hypothesis of y_t not causing x_t in variance at j to k lags. A rejection of the null hypothesis is interpreted as a significant indication of stock market volatility spillover from y_t to x_t at j to k lags.

In addition to the explicit modeling of conditional volatility by the GARCH technique, the residual CCF tests proposed by Cheung and Ng (1996) described above have several desirable features for the purpose of the current study. The tests identify causal directions and lag structures, which are important factors for understanding the shock propagation patterns across various stock markets. Also, spillover of market volatility can be formally tested by the s_{σ^2} statistic. Further, as compared to alternative approaches such as use of multivariate GARCH models, the CCF tests avoid over-parameterization by practicing parsimonious modeling. Finally, the CCF tests are asymptotically robust to distributional assumptions, and the Monte Carlo experiments by Cheung and Ng (1994) show that they possess good empirical size and power properties.

4. Results for the Entire Sample Period

As an initial set of empirical evidence, this section presents the results obtained using the entire sample data. Table 3 displays the estimation results of (1) for the Asian and Latin American markets using the 1990-2001 sample. For most markets, the SBIC selects AR(1)-GARCH(1, 1) specification. The data on Thailand and Argentina, however, exhibit strong serial correlations, and consequently, AR(2)-GARCH(1, 1) and AR(3)-GARCH (1, 1) are adopted, respectively. Except for Brazil, the LB Q-statistic and Q^2-statistic indicate no further serial correlations in the resulting standardized residuals and their squares, respectively, at the conventional levels of significance. The Brazilian stock return exhibits highly persistent ARCH effects that is not fully captured by GARCH(1, 1) specification. The problem is not easily resolved by fitting alternative GARCH specifications. Thus, we tentatively report the result for AR(1)-GARCH(1, 1), while noting that a caution needs to be exercised when interpreting the causality in variance test results for Brazil. We will return to the issue in section 5 where we discuss the possibility of parameter instability of the stock return models.

Using the standardized residuals and their squares obtained from the estimated AR-GARCH models, we next implement the CCF tests to examine inter-market causality in mean and variance. Testing for causality in both mean and variance for all market pairs at lags and leads will generate a voluminous amount of information. To highlight essential information, we define the regions' focal markets and focus on their linkages with others.[11] Considering how the 1994-95 Mexican and the 1997-98 Asian crises - arguably the two most momentous crises in the sample - were initiated, we define Thailand and Mexico to be the focal markets of Asia and Latin America, respectively.

4.a Causal Linkages within Each Region

We begin with the results for cross-market causality within each region, summarized in Table 4. In conducting the tests, we set *j=k* in (5) and (6) and the

[11] The results for other market pairs, not reported due to space limitation, are available upon request.

maximum lag to be five trading days. Thus, the reported statistics are for causality at a specific lag k, where $0 \leq |k| \leq 5$. The test results are organized by market-pair and lag order. For a pair of markets in the same region, a significant test statistic with lag $k < 0$ should be interpreted that the stock return of the first-listed market causes that of the second-listed in mean and/or variance with a $|k|$-period lag. Similarly, if the test statistic is significant with $k > 0$, the second country's stock return is found to cause the first country's in mean/variance with a k-th lag. A significant test statistic with k=0 indicates contemporaneous causality.

Panel A of Table 4 presents the causality in mean test results. Apparently, market returns in the same region share significant contemporaneous causality in mean. This is consistent with the sizeable contemporaneous correlations between markets within a region reported in this and many previous studies. In addition, the test statistics are significant also for one-day lag and lead for the Asian pairs. For the Latin American pairs, the causal pattern does not appear uniformly symmetric. Besides the significant instantaneous causality, Mexico causes others with one period lag. However, the reversed causality with k=1 is significant only from Argentina. Overall, the results suggest that shocks travel across markets in the same region within one trading day.

The causality in variance test results reported in Panel B of Table 4 suggest that market volatility is also shared in a contemporaneous fashion within each region. The pattern of non-contemporaneous causality, however, varies substantially by market pair. While the overall causal pattern defined by the significance, directions, and lag structures, is not unanimous, it is indicated that intra-regional market interactions over the past twelve-year period have taken place not only in the first moment but also in the second moment of stock returns.

4.b Causal Linkages between Asia and Latin America

Let us turn our attention to causality across regional boundaries. Tables 5 and 6 summarize the results of inter-regional CCF tests. It is noted that the Asian markets and the Latin American markets operate in different time zones while the market operating-hours overlap within each region.[12] The interpretation of the lag k has to be modified accordingly. Specifically, significant inter-regional cross-market correlation on the same calendar day (i.e. $k=0$) should be interpreted as evidence of the Asian market causing the Latin American market, but not vice versa. Thus, for a given pair of markets, a significant test statistic with lag $k \leq 0$ indicates that the stock return of the first-listed Asian market causes that of the second-listed Latin American. If the test statistic is significant with $k \geq 1$, the Latin American market's stock return is found to cause the Asian one.

Table 5 presents strong evidence that the Asian markets and the Latin American markets cause each other in mean. For all inter-regional market pairs, the causality in mean test statistics are significant for both $k=0$ and $k=1$. In other words, market disturbances realized in Asia hours ago significantly affects the return for the Latin American markets now. Similarly, shocks to the Latin American markets now exert significant influence on how the Asian markets will do tomorrow. It is noted that highly significant inter-regional causality in mean is observed mostly within a twenty-four hour lag or lead.

The results of the inter-regional causality in variance test are reported in Table

[12] The market operating hours in local times are as follows: Hong Kong 10:00-12:30, 14:30-16:00; Malaysia 9:00-12:30, 14:30-16:30; the Philippines 9:30-12:00; Thailand 10:30-12:30, 14:30-16:30; Argentina 14:00-18:00; Brazil 11:00-13:30, 14:30-17:45; Chile 9:30-17:30; Mexico 8:30-15:00. Hong Kong, Malaysia, and the Philippines are in the same time zone. Thailand lags behind them by one hour. Argentina and Brazil are ten hours behind Thailand. Chile and Mexico lag behind Argentina by one hour and two hours, respectively.

6. It is revealed that, unlike the two-way causality in mean, significant causality in variance runs primarily from the Latin American markets to the Asian markets. In fact, for the majority of the examined market pairs, causality in variance is significant only in one direction, from Latin America to Asia, with k=1. The results suggest that while the Asian markets contract volatility in Latin America significantly and swiftly, volatility spillover in the opposite direction is less likely. These observations apply also to the direct relationship between the two focal markets such that Mexico causes Thailand in variance, but not vice versa. The result reveals that, despite the strong two-way causality in mean, the relationship between the two regions is not symmetric since the information flow that drives the behavior of conditional variance is uni-directional.

5. Market Linkages in and out of Crises: Evidence from Rolling CCF Tests

The results in the previous section provide a general idea of the intra and inter-regional causality among the markets in Asia and Latin America over the past twelve-year period. They suggest the presence of significant market linkages within each region and across the two. During the 1990-2001 period, however, the market environments fluctuated considerably as rapid growth was repeatedly interrupted by market disorder such as the 1994-95 Mexican and the 1997-98 Asian crises. Consequently, it is conceivable that the dynamics of stock return processes also shifted over time. Therefore, in this section we remove parameter stability constraints from the stock return models, and examine how the inter-market causal dynamics has evolved since 1990 as the markets experience booms and busts. It is noted that, within our sample, crisis incidents are distributed primarily in the following three time intervals: 1990-91 (Argentina and Brazil); 1994-95 (Mexico, Argentina, and Brazil); and 1997-98

(Thailand, Malaysia, and the Philippines). These sub-periods are considered as turning points of market environment when interpreting the empirical results below.

Addressing the possibility of shifting model parameter is worthwhile due also to the following reason. The estimation results of the stock return models reported in Table 3 imply that the conditional variance processes are highly persistent. Specifically, the obtained GARCH parameters are often such that the estimates of α_1 and β sum up close to unity, exhibiting a symptom of the so-called integrated GARCH (IGARCH) process. This applies especially to the Brazilian data, whose conditional variance process is so persistent that it is not fully captured by GARCH(1, 1) specification as mentioned in section 4. Diebold (1986) and Lamoureux and Lastrapes (1990) point out that such seemingly excessive persistence may be a result of a structural break in the conditional variance processes. If this is indeed the case, imposing parameter stability over the entire sample period may lead to inaccurate inferences.

To trace how the cross-market causal linkages have evolved since 1990 while alleviating effects of possible parameter instability, we conduct rolling CCF tests as follows. Starting from January 1990, we perform the residual CCF test using a fixed window of 240 observations and roll it through the entire sample period.[13] With an addition/deletion of each observation, the AR-GARCH models are re-estimated to update all parameters.[14] The resulting standardized residuals and their squares are used to test for cross-market causality for the corresponding 240-trading day sub-periods. To

[13] The 240-observation window corresponds roughly to a one-year period in calendar time. In deciding the length of the rolling window, there is a trade off between the degrees of freedom for the AR-GARCH estimations and possibility of including a structural break within the window. A longer window provides a greater degree of freedom in estimating the AR-GARCH models. However, it will also create a greater number of sub-periods that contain a possible structural break.

[14] The AR-GARCH model specifications selected in section 4 are used for all sub-periods. Since the parameter values are renewed in each estimate, the resulting (squared) standardized residuals and their correlations change over samples.

summarize the results succinctly, we plot the significance level of the causality test statistics as time series.

5.a Evolution of the Causal Linkages within Each Region

Before discussing the results in detail, it is worth mentioning that the symptom of IGARCH is indeed alleviated in the rolling estimations. In general, the sum of the estimates of α_1 and β stay well below unity, and the resulting LB Q^2-statistic suggests that the GARCH (1, 1) specification is sufficient to capture the conditional variance dynamics for the Brazilian data as well as others.

Figure 2 portrays the time series behavior of the significance of the intra-Asian causality in mean/variance statistic under the null hypothesis of no causality within two trading-day lags.[15] In Figure 2.A, the p-values of the test statistics for causality in mean from Thailand are plotted by destination market. Figure 2.B depicts the significance of the reversed causality. The labels on the horizontal axis denote the beginning dates of the 240-trading-day rolling window. The two figures, which appear largely symmetric, indicate that the intra-Asian causality in mean concertedly turn highly significant in three sub-periods: 1990; mid-1993 through 1995; and from early 1997 to mid-1998 or later.

As Figure 1.A shows, the first sub-period of 1990 contains the joint decline of the Asian stock indices, including a plunge of the Philippine and Thai markets.[16] The second sub-period corresponds to the collective market slide of early 1994, and the subsequent market mayhem started in Mexico. It is noted that the causal relationships

---

[15] The displayed results in Figures 2 and 3 are for $j = 0$ and $k = 2$. We consider $k = 2$ an appropriate choice based on the results in section 4 that significant causality is observed within two lags/leads in most cases. Increasing k would mask the significance of causality at a shorter lag. On the other hand, k=1 is too restrictive to fully capture non-synchronous causality.
[16] The incidents roughly coincide in timing with the currency crises in Argentina and Brazil.

become insignificant between the first and second sub-periods as the Asian markets experience fairly steady growth as seen in Figure 1.A. The third sub-period of 1997-98 coincides with the Asian crisis. These results altogether seem to suggest that the causal interactions in mean within Asia are intensified when the markets are faced with adverse environment.

The remaining two figures 2.C and 2.D describe time variation of the intra-Asian causality in variance from and to Thailand, respectively. The significance of the test statistic appears highly time dependent, and it often varies widely also by market pair. Nevertheless, in Figure 2.C unanimously significant results in two occasions are discernible. In mid-1993 the causality in variance for all destinations become significant and remain largely so through 1995. After an interval, the significant results simultaneously recur in the spring of 1997 to last for approximately one year.[17] These sub-periods of firm market linkages in variance coincide in timing with the Mexican and Asian crises. In view of these results, it should be noted that the causality in variance within Asia become highly significant not only at the time of the Asian crisis, but also around the time of the Mexican crisis.

Figures 3.A and 3.B plot the significance of intra-Latin American causality in mean directed from and to Mexico, respectively. The message in the figures is clear. The causality-in-mean relationships were unstable and generally insignificant until 1993. In the summer of 1993, however, they become highly significant in a remarkably concerted fashion.[18] Except for the temporarily insignificant Mexico-Chile relationship

---

[17] As seen in Figure 2.D, the significant causality from Thailand is reciprocated by Hong Kong and the Philippines, but not by Malaysia.

[18] It is reminded that we refer to 240-trading day sub-samples by their beginning dates. Thus, this result should be interpreted that the test statistic becomes highly significant as the sample draw more observations from 1994 and fewer from 1993.

in 1995, the intra-Latin American causal linkages have remained highly significant ever since mid-1993, exhibiting no sign of instability. In other words, the market relationships appear to have been permanently transformed. This point, although important, has not been well taken into consideration by previous studies when assessing market contagion. When disturbances leave persistent effects on the market linkages, it becomes rather difficult to provide an accurate evaluation of the contagion hypothesis by simply comparing only two particular sub-samples. By illustrating the behavior of market linkages continuously through the whole sample period, our empirical results reveal a more comprehensive picture of the issue.

The evidence of causality in variance within Latin America is summarized by Figures 3.C and 3.D. Similarly to the causality-in-mean case, the causality-in-variance test results are generally insignificant until mid-1993. Then, the market linkages seem to be firmly built in 1994 through the first quarter of 1995. After experiencing instability for some market pairs, the test statistics become highly significant in a unanimous fashion in early 1997. It should be noted, however, that unlike the causality-in-mean case, Mexico's causality-in-variance relationships with Argentina and Chile become insignificant again in 1999 as the markets enter the post-Asian crisis era. On the other hand, the linkage with Brazil, which experienced a currency crisis and a consequent stock plunge in 1999, has remained highly significant.

In sum, we note that the periods of significant market linkages very often coincide with the periods of major financial crises. Specifically, we note that, both within Asia and within Latin America, the causality in mean between markets is clearly strengthened around the time of the 1994-95 Mexican and the 1997-98 Asian crises. Although not as unequivocal as the causality in mean, the intra-regional causality in variance also exhibits a tendency to intensify at the time of the two major crises. Taken altogether, the evidence from the rolling tests suggests that the market linkages in the same geographical region tend to be firmly established when markets suffer from crises. It should be emphasized that both the intra-Asia and intra-Latin America stock return causality becomes highly significant in both the Mexican crisis and the Asian crisis periods. The results seem to imply that a crisis in one region can establish significant causal linkages between stock markets within its own region as well as within the other.

5.b Evolution of the Causal Linkages between Asia and Latin America

We next examine the time series behavior of the inter-regional market linkages. Specifically, we study how the significance of causality from each region's focal market to markets in the other region has fluctuated. Figures 4.A and 4.B plot the p-values of the CCF test statistic under the null hypothesis of no causality in mean and variance, respectively, from Thailand to the Latin American markets at the first to third lags.[19] The first observation to note regarding Figure 4.A is that significance of the inter-regional causal relationships in mean appears far less stable than the intra-regional counterpart. It varies widely over time and by market-pair. Nevertheless, the figure decidedly points to one striking phenomenon. From early 1997 to mid-1998, the causality in mean from Thailand to Latin America becomes highly significant in a remarkably concerted fashion. The results imply that as the financial crises sprawled in Asia, the Latin American markets became linked to the troubling Asian markets, and consequently, they were exposed to negative effects of the crises in Asia. It is emphasized that the change in the significance of the causal relationships at the time of

[19] For causality from Asia to Latin America, the p-values for $j = 0$ and $k = 2$ are plotted. For causality in the opposite direction, Figure 5 plots the p-values for $j = 1$ and $k = 3$ due to the non-synchronous trading hours of the two regions.

the Asian crisis is quite drastic and unambiguous. While there are other sub-periods for which the test results are significant for some market-pairs, none contains similarly striking and unanimous indications of robust market linkages. It is also important to observe that the emergence of the significant causal linkages is only temporary, unlike the intra-regional cases seen in the previous subsection.

Figure 4.B portrays how the significance of the causality in variance from Thailand to the Latin American markets behaved. Consistently with the entire-sample results reported in Table 6, significant causality in variance destined to Latin America, although occasionally observed, is rather sporadic. Aside from the one destined to Mexico for early 1990 to mid-1991, the volatility spillover from Thailand to Latin America does not seem to be firmly established.

Evolution of causality in the reverse direction, from Mexico to Asia, is portrayed in Figure 5. The significance of causality in mean, in Figure 5.A, appears highly time varying and destination specific. While exhibiting significance in part of 1990, the causal linkages become largely insignificant and unstable in the following years.[20] In 1995, however, the from-Mexico-to-Asia causality in mean became highly significant in a unanimous fashion. Although the significance level declines in 1996, it is revived in 1997 through 1999, except for the one to Malaysia. Although not as unequivocal as in the intra-Latin American cases, the figure seems to suggest that the causality in mean from Mexico to Asia, excluding Malaysia, is more stably established after 1995 than before.

As enunciated by Figure 5.B, the causality in variance from Mexico to Asia also appears rather erratic. Nevertheless, as compared to inter-regional causality in

[20] An exception is the significant causality from Mexico to Hong Kong throughout 1993.

variance in the opposite direction (shown in Figures 4.B), significant results are more often observed, especially in the second half of the sample. While volatility of the Mexican market hardly influenced that of the Asian markets before, in 1995, Mexico came to cause the Asian markets in variance. Although market linkages do not seem firmly established for all destinations, the causality in variance to Hong Kong during 1995-1996 is evident. Later in 1997, the causality in variance from Mexico to the Asian markets, except for Malaysia, becomes unambiguously significant. Taken together with the from-Thailand-to-Latin America results above, it seems that the volatility spillover around the time of the Asian crisis took place primarily in one direction, from Latin America to Asia. That is, the ones in the middle of the crisis were the recipients rather than the senders of market volatility. The finding should be contrasted with the Asia-causing-Latin America-in-mean results.

Overall, we find the causality across the regions to vary more considerably over time and by market-pairs than the causality within each region. Nevertheless, as the Asian crisis is initiated in 1997, the causality in mean from Thailand to Latin American markets becomes highly significant in an unmistakable fashion. As demonstrated by Figure 4.A, the causality-in-mean relationships between Thailand and Latin America during the Asian crisis appears strikingly different from those before or after the crisis. The evidence is consistent with the prediction of the contagion hypothesis. Further, it suggests that significant market linkages are established even across regional boundaries. The same observation, however, does not apply to causality in variance. Except for Chile to some extent, the Latin American markets do not seem susceptible to volatility of the Thai market during the 1997-98 crisis. Regarding the time variation of the inter-regional causality in the opposite direction, from Latin America to

Asia, the message carried by the empirical results is not as unequivocal. Nevertheless, we tend to see that the Mexican market has been more influential to the Asian markets since 1995 than it was in the previous period. Taken into account together with the intra-Latin American results, it seems that the experience of the Mexican crisis had rather fundamental effects of enhancing various inter-market linkages.

6. Conclusion

One intriguing empirical observation over the past decades is that financial crises in emerging markets often occur in a clustered fashion in timing. A natural supposition is that there are significant cross-country casual interactions, or contagion, in the financial markets as they experience turbulence in a seemingly concurrent or successive fashion. Whether or not the supposition holds true has critical implications for the ongoing debate over the desirability of swift financial market liberalization in many emerging economies. To gain insight into the issue, it is instructive to investigate how shocks and volatility travel across emerging financial markets within a region as well as across a regional boundary.

In this study, we examine the causal linkages among several emerging stock markets in Asia and Latin America using the daily observations of their stock indices over the past twelve-year period. After modeling the dynamics of the daily stock return using the GARCH techniques, we conduct the cross-correlation function tests for causality in the first and second moments at various lags and leads using the standardized residuals and their squares. The empirical results suggest that there are indeed considerable causal interactions across the emerging stock markets. When the data for the entire 1990-2001 sample are used, the markets within each region are generally found to share significant causality in mean and variance of their stock returns. Regarding interactions between the Asian and Latin American markets, the empirical evidence suggests that shocks to the market return in one region exerts a significant influence on the return in the other region immediately on the following trading day. Remarkably, however, the transmission of market volatility between the two regions is found to flow mostly in one direction, from Latin America to Asia.

To better understand if and how the pattern of market interactions alters significantly as the markets go through volatile and stable periods, we extend our exercise by conducting the causality tests with a rolling window. It is evidenced that the significance of the causal linkages between markets varies substantially over the sample period. Importantly, there are considerable indications that the causal linkages are strengthened around the time of major financial crises such as the 1994-95 Mexican and the 1997-98 Asian crises. The tendency is clearly seen for the intra-Asia market relationships both in mean and variance, as well as the intra-Latin America market relationships in variance. The causality in mean within Latin America, on the other hand, seems to be permanently transformed once the markets experience the Mexican crisis. Furthermore, as clearly seen in the example of causality in mean from Thailand to Latin America (Figure 4.A), enhancement of market linkages under turmoil is not necessarily contained within regional boundaries. In view of all the empirical evidence, we conclude that the causal interactions among emerging stock markets in Asia and Latin America under crisis circumstances seem to differ from those in stable times. Within each region as well as across the two regions, the market returns appear to become more interdependent on each other.

As an additional note, our empirical results also underscore the complexity of inter-market relationships. Specifically, time-dependent market linkages may be established through mean and/or variance of stock returns, and the relationships can be asymmetric between regions. Also, shocks on market linkages can be temporary or highly persistent. These various possibilities should be taken into consideration when investigating market contagion.

The exercise conducted in this paper provides useful information for understanding the nature of dynamic interactions among the emerging financial markets within and across the Asian and Latin American regions. Unlike the correlation analyses between two particular sub-samples, our empirical procedure illustrates how the market linkages, via the first and second moments of stock return, have evolved over the past twelve years. With the use of the daily frequency data, the CCF tests identify causal structure between markets operating in different time zones while explicitly accounting for conditional heteroskedasticity.

Unfortunately, implementation of our empirical exercise also bears a cost. Since data on key macroeconomic variables are not available at a daily frequency, we are unable to infer to the sources of market shocks and volatility. Thus, our finding simply portrays changes in the pattern of causal interactions across markets over time. As a possible extension in the future, it would be useful to see if data on other financial variables such as exchange rates and interest rates depict a similar picture.

References

Baig, Taimur and Ilan Goldfajn, 1999. "Financial market contagion in the Asian Crisis." *Staff Papers*, International Monetary Fund, 46: 167-195.

Bollerslev, Tim, Ray Y. Chou, and Kenneth F. Kroner, 1992. "ARCH modeling in finance: A review of the theory and empirical evidence." *Journal of Econometrics* 52: 5-59.

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*. Washington, D.C.: Institute for International Economics.

Campbell, John Y., Andrew W. Lo, and A. Craig MacKinlay, 1997. *The Econometrics of Financial Markets*. Princeton, New Jersey: Princeton University Press.

Cheung, Yin-Wong and Kon S. Lai, 1995. "Lag order and critical values of a modified Dickey-Fuller test." *Oxford Bulletin of Economics and Statistics* 57: 411-419.

Cheung, Yin-Wong and Lilian K. Ng, 1994. "A causality-in-variance test and its application to financial market prices." Manuscript, University of California, Santa Cruz.

Cheung, Yin-Wong and Lilian K. Ng, 1996. "A causality-in-variance test and its application to financial market prices." *Journal of Econometrics* 72: 33-48.

Diebold, Francis, X., 1986. "Modelling the persistence of conditional variances: a comment." *Econometric Review* 5: 51-56.

Edwards, Sebastian and Raul Susmel, 2001. "Volatility dependence and contagion in emerging markets." *Journal of Development Economics* 66: 502-532.

Elliott, Graham, Thomas J. Rothenberg, and James H. Stock, 1996. "Efficient tests for an autoregressive unit root." *Econometrica* 64: 813-836.

Engle, Robert F., 1982. "Autoregressive Conditional Heteroskedasticity with Estimates of the Variance of UK Inflation", *Econometrica* 50: 987-1008.

Forbes, Kristin and Roberto Rigobon, 2002. "No contagion, only interdependence: Measuring stock market comovement." *Journal of Finance*, forthcoming.

Furman, Jason and Joseph E. Stiglitz, 1998. "Economic Crises: Evidence and Insights from East Asia." *Brookings Papers on Economic Activity* 2: 1-113.

Goldstein, Morris, Graciela L. Kaminsky, and Carmen M. Reinhart, 2000. *Assessing Financial Vulnerability: An Early Warning System for Emerging Markets.* Washington, D.C.: Institute for International Economics.

Granger, Clive W.J., 1969 "Investigating Causal Relations by Economic Models and Cross-spectral Methods." *Econometrcia* 37: 424-438.

Hamao, Y., R.W. Masulis, and V. Ng, 1990. "Correlations in price changes and volatility across international markets." *Review of Financial Studies* 3: 281-307.

Kaplanis, Evi C., 1988. "Stability of forecasting of the co-movement measures of international stock market return." *Journal of International Money and Finance* 8: 63-75.

King, Mervyn. A. and Sushil Wadhwani, 1990. "Transmission of volatility between stock markets." *Review of Financial Studies* 3: 5-33.

King, Mervyn. A., Enrique Sentana, and Sushil Wadhwani, 1994. "Volatility and links between national stock markets." *Econometrica* 62: 901-934.

Koch, Paul D. and Timothy W. Koch, 1991. "Evolution in dynamic linkage across national stock indexes." *Journal of International Money and Finance* 10: 901-934.

Lamoureux, Christopher G. and William D. Lastrapes, 1990. "Persistence in variance, structural change, and the GARCH model." *Journal of Business & Economic Statistics* 8: 225-234.

Lee, Sang-Bin and Kwang-Jung Kim, 1993. "Does the October 1987 Crash Strengthen the Co-movements among National Stock Markets?" *Review of Financial Economics* 3: 89-102.

Longin, François and Bruno Solnik, 1995. "Is the correlation in international equity returns constant: 1960-1990?" *Journal of International Money and Finance* 14: 3-23.

Masson, Paul, 1998. "Contagion: Monsoonal effects, spillovers, and jumps between multiple equilibria." *IMF Working Paper* 142. Washington, D.C.: International Monetary Fund.

Ramchand, Latha and Raul Susmel, 1998. "Volatility and cross correlation across major stock markets." *Journal of Empirical Finance* 5: 397-416.

Radelet, S. and Jeffery Sachs, 1998. "The East Asian Financial Crisis: Diagnosis, Remedies, Prospects." *Brookings Papers on Economic Activity* 1: 1-74.

Table 1 Descriptive Statistics

	Mean	Std. Dev.	Skewness	Kurtosis	Normality	LB-Q(10)	LB-Q^2(10)
Asia							
Hong Kong	0.0317	0.0172	-0.0457	8.4503	**	38.0455**	915.594**
Malaysia	-0.0084	0.0213	-0.7187	51.4698	**	88.6108**	155.302**
Philippines	-0.0245	0.0172	0.8020	13.6505	**	139.598**	178.394**
Thailand	-0.0549	0.0224	0.4427	6.6383	**	109.975**	1135.73**
Latin America							
Argentina	0.0215	0.0334	-5.8169	201.9157	**	135.027**	164.454**
Brazil	0.0279	0.0291	-0.3761	8.0527	**	82.775**	1016.14**
Chile	0.0367	0.0125	0.0401	6.1661	**	201.684**	392.839**
Mexico	0.0524	0.0202	-0.1088	13.4732	**	55.000**	490.063**

Notes: Descriptive statistics of the daily stock returns are provided for the countries noted in the first column. "Std. Dev." is the standard deviation. Mean and standard deviations are in percentage terms. LB-Q(10) and LB-Q^2(10) give the Ljung-Box Q-statistics calculated from the first 10 autocorrelations of the estimated standardized residuals and their squares, respectively. The entry under "Normality" indicates the significance of the Jarque-Bera test for normality. ** indicates the statistical significance at one percent level.

Table 2

Correlation Matrix of the Stock Returns

	Hong Kong	Malaysia	Philippi.	Thailand	Argenti.	Brazil	Chile	Mexico
Malaysia	0.3470							
Philippines	0.2958	0.2367						
Thailand	0.3564	0.3649	0.3208					
Argentina	0.0738	0.0504	0.0501	0.0668				
Brazil	0.1089	0.0598	0.0593	0.0845	0.2255			
Chile	0.1726	0.0885	0.1126	0.1425	0.2598	0.3062		
Mexico	0.1562	0.1043	0.1012	0.1098	0.2812	0.3934	0.3447	

Note: Each entry gives a sample correlation between the daily stock returns of the corresponding markets.

Table 3 Estimation Results of AR-GARCH Models

Parameter	Hong Kong	Malaysia	Philippines	Thailand	Argentina	Brazil	Chile	Mexico
ϕ_0	0.0008**	0.0005**	0.0002	0.0000	0.0007*	0.0009**	0.0000	0.0012**
	(0.0002)	(0.0002)	(0.0004)	(0.0002)	(0.0003)	(0.0003)	(0.0002)	(0.0002)
ϕ_1	0.0922**	0.2013**	0.1939**	0.1356**	0.1105**	0.1296**	0.2474**	0.1802**
	(0.0219)	(0.0217)	(0.0268)	(0.0207)	(0.0200)	(0.0196)	(0.0329)	(0.0224)
ϕ_2	-	-	-	0.0577**	-0.0474	-	-	-
				(0.0216)	(0.0267)			
ϕ_3	-	-	-	-	0.0510*	-	-	-
					(0.0244)			
α_0	0.0000**	0.0000*	0.0000**	0.0000*	0.0000**	0.0000	0.0000	0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
α_1	0.1092**	0.1048**	0.1294**	0.1144**	0.1430**	0.1300**	0.1291	0.1953**
	(0.0207)	(0.0129)	(0.0213)	(0.0257)	(0.0210)	(0.0196)	(0.1362)	(0.0508)
β	0.8692**	0.8974**	0.8699**	0.8755**	0.8461**	0.8739**	0.8393**	0.7485**
	(0.0247)	(0.0136)	(0.0243)	(0.0290)	(0.0195)	(0.0202)	(0.2116)	(0.0557)
LB-Q(10)	10.8741	14.0635	11.8897	17.4154	16.3710	12.9777	14.1852	15.4066
LB-Q^2 (10)	3.5230	10.8047	0.5494	17.6290	12.6340	19.8025*	3.1412	13.3926

Notes: The estimated coefficients and standard errors in parentheses are reported for (1) in the main text. LB-Q(10) and LB-Q^2(10) give the Ljung-Box Q-statistics calculated from the first 10 autocorrelations of the estimated standardized residuals and their squares, respectively. ** and * indicate statistical significance at 1 % and 5 % levels, respectively.

Table 4

Intra-Regional Causality Test Results

Lag *k*	Thailand/ Hong Kong	Thailand/ Malaysia	Thailand/ Philippines	Mexico/ Argentina	Mexico/ Brazil	Mexico/ Chile
A. Causality in Mean						
-5	0.0002	1.4849	0.9877	1.7695	0.3581	2.3776
-4	2.2781	0.0134	0.5135	2.9143	0.4599	0.0693
-3	0.3525	0.4399	1.7141	0.1825	0.0638	1.4156
-2	3.4378	2.9258	0.9299	2.1027	0.1853	0.0928
-1	6.7212**	4.8442*	41.6771**	25.5941**	25.7498**	20.1899**
0	319.336**	270.652**	131.203**	360.231**	402.538**	233.127**
1	37.5247**	25.5580**	6.9469**	5.6424*	1.0865	0.1213
2	1.2866	0.1965	2.0916	0.3011	0.0058	0.2411
3	0.7254	0.2293	2.5761	2.8104	0.5053	0.0038
4	0.0203	0.3095	0.1322	2.2216	0.7377	0.0284
5	1.2291	3.7752	0.1542	0.9165	0.0752	0.2336
B. Causality in Variance						
-5	0.1820	0.9962	0.0639	0.8964	0.5753	0.7608
-4	0.5628	0.5130	0.0079	0.5574	1.6295	0.2600
-3	0.4247	0.0017	8.8226**	0.0741	0.0575	0.5102
-2	2.6569	2.1092	0.1215	2.6429	0.9600	0.0761
-1	1.5091	0.4619	3.3625	13.5426**	4.5129*	0.1775
0	227.536**	74.8377**	6.2313*	267.648**	225.715**	73.3569**
1	27.5124**	2.4942	0.0052	3.7523	0.2417	3.8669*
2	7.2683**	0.4433	0.5254	8.9002**	24.2562**	0.0027
3	1.2884	0.0978	0.0482	0.0679	1.2806	0.1333
4	0.0129	0.1662	1.0163	0.1549	0.1801	0.0015
5	2.4192	0.1544	0.0036	0.1633	1.1439	0.5045

Notes: Each entry in Panels A and B respectively gives the causality in mean and causality in variance statistics, defined by (5) and (6) in the main text, between the stock returns of the countries noted in the top row. The lag *k* denotes the number of periods by which the stock return of the first market lags or leads that of the second market. A negative (positive) value of *k* indicates lags (leads). ** and * indicate statistical significance at 1 %, and 5 % levels, respectively. The sample period is from January 1, 1990 to November 14, 2001.

Table 5 Inter-Regional Causality in Mean Test Results

Lag	Thailand/ Argentina	Thailand/ Brazil	Thailand/ Chile	Thailand/ Mexico	Hong Kong/ Mexico	Malaysia/ Mexico	Philippines/ Mexico
-5	0.1487	0.4614	7.434**	1.2348	0.0098	3.1890	1.8286
-4	0.0052	0.5015	2.3671	0.5127	1.2332	0.6074	0.1593
-3	0.3631	0.0619	0.5783	0.0659	0.5936	0.4197	0.9671
-2	0.1021	0.7162	0.4445	1.6977	1.2650	0.9237	1.3821
-1	0.5501	1.3994	0.2146	0.3270	0.0000	0.7088	0.9307
0	27.4757**	31.6773**	45.3213**	30.9769**	69.2352**	38.0248**	17.0803**
1	45.7044**	23.9973**	43.0869**	74.7691**	164.5102**	51.2159**	70.4784**
2	7.5820**	6.2501*	1.1286	3.1779	0.0026	1.4921	1.4134
3	3.0534	1.9657	1.0244	5.4847*	1.0846	2.8800	1.2603
4	0.4621	0.4836	1.1906	5.6467*	0.4416	0.0075	0.0459
5	0.6366	0.1547	0.3690	0.2467	0.1273	0.2030	0.3342

Notes: Each entry gives the causality in mean statistic, defined by (5) in the main text, between the stock returns of the countries noted in the top row. The lag k denotes the number of periods by which the stock return of the first market lags or leads that of the second market. A negative (positive) value of k indicates lags (leads). ** and * indicate statistical significance at 1 % and 5 % levels, respectively. The sample period is from January 1, 1990 to November 14, 2001.

Table 6 Inter-Regional Causality in Variance Test Results

Lag	Thailand/ Argentina	Thailand/ Brazil	Thailand/ Chile	Thailand/ Mexico	Hong Kong/ Mexico	Malaysia/ Mexico	Philippines/ Mexico
-5	0.0600	0.0000	0.4668	0.6882	1.2841	0.7964	0.7330
-4	0.9928	0.0075	0.0438	0.0113	0.3909	0.6920	0.0520
-3	0.7027	1.5483	0.0340	0.9102	3.7749	0.0179	0.9779
-2	0.0973	0.5663	0.2924	0.4911	3.2526	0.0012	0.0202
-1	5.6316*	0.8921	0.9948	0.0141	0.2429	2.7239	0.0589
0	9.2205**	1.3208	0.6311	2.9418	22.4633**	0.7341	0.0022
1	27.5019**	11.0055**	55.1160**	73.6690**	107.5454**	2.9015	8.0163**
2	4.5895*	0.3682	0.8035	0.7396	0.2233	0.0378	0.0838
3	1.2041	0.4108	0.3095	2.3251	2.0339	0.7029	0.0034
4	2.0603	0.0279	1.9982	0.4502	0.1691	0.6781	0.0073
5	0.2691	1.4379	0.6174	0.0135	0.2118	6.4528*	0.1347

Notes: Each entry gives the causality in variance statistic, defined by (6) in the main text, between the stock returns of the countries noted in the top row. The lag k denotes the number of periods by which the stock return of the first market lags or leads that of the second market. A negative (positive) value of k indicates lags (leads). ** and * indicate statistical significance at 1 % and 5 % levels, respectively. The sample period is from January 1, 1990 to November 14, 2001.

Figure 1.A
Asian Stock Indices

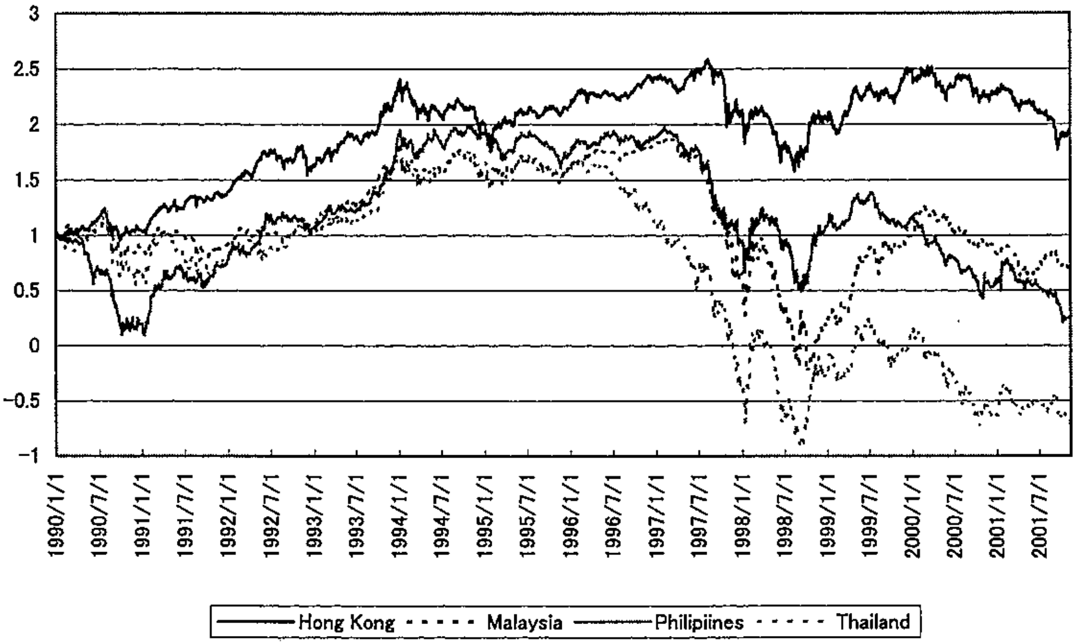
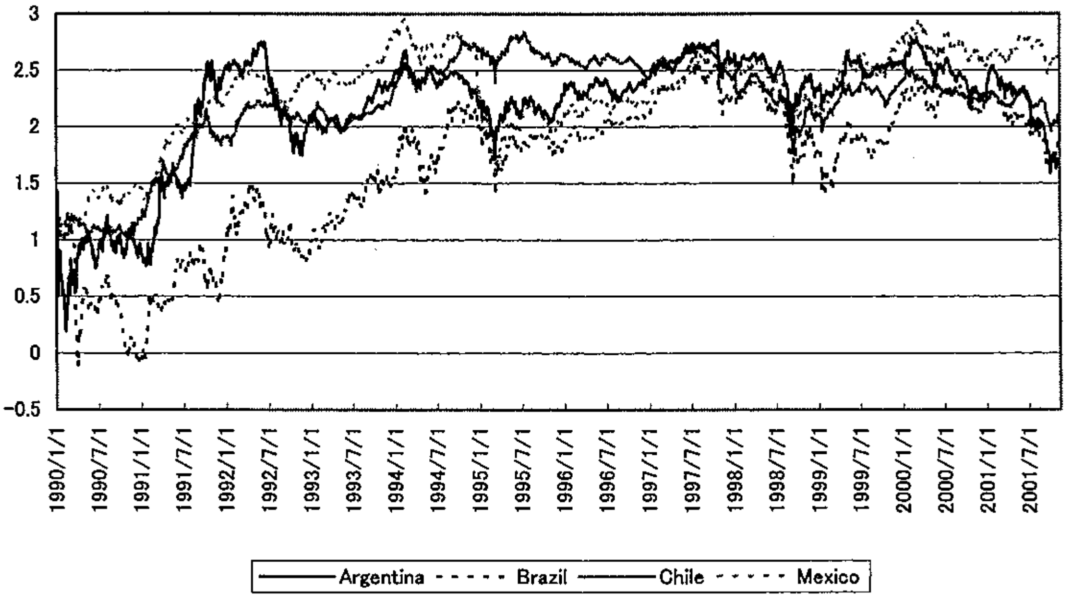


Figure 1.B
Latin American Stock Indices



Note on Figure 1: Figures 1.A and 1.B plot Asian and Latin American stock indices, respectively. All stock indices are normalized to be unity on January 1, 1990.

Figure 2.A
Causality in Mean from Thailand

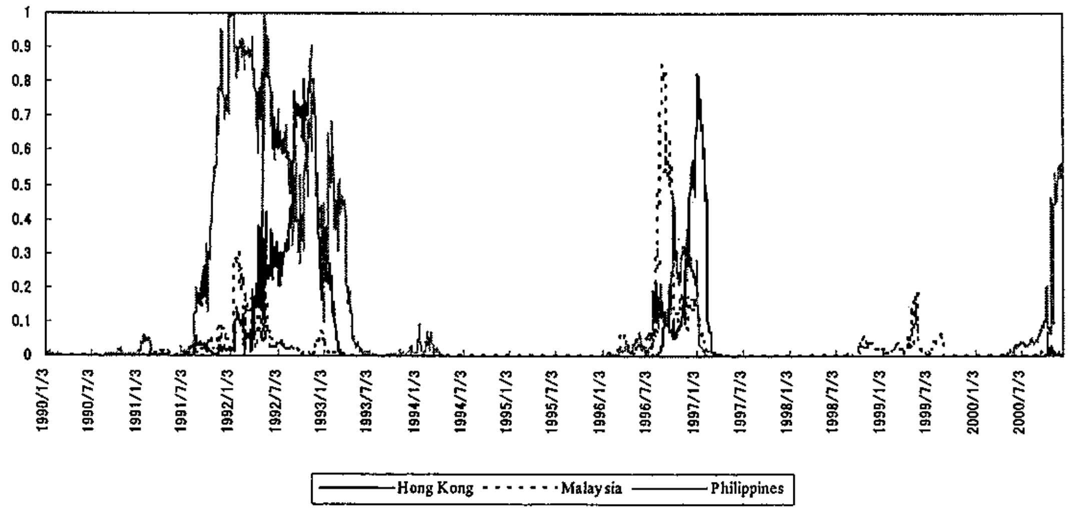


Figure 2.B
Causality in Mean to Thailand

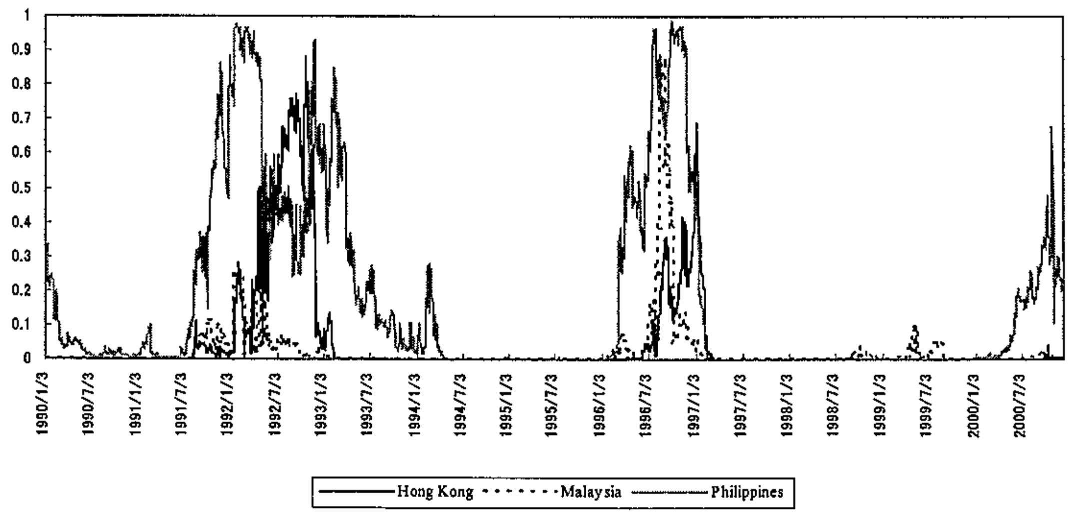


Figure 2.C
Causality in Variance from Thailand

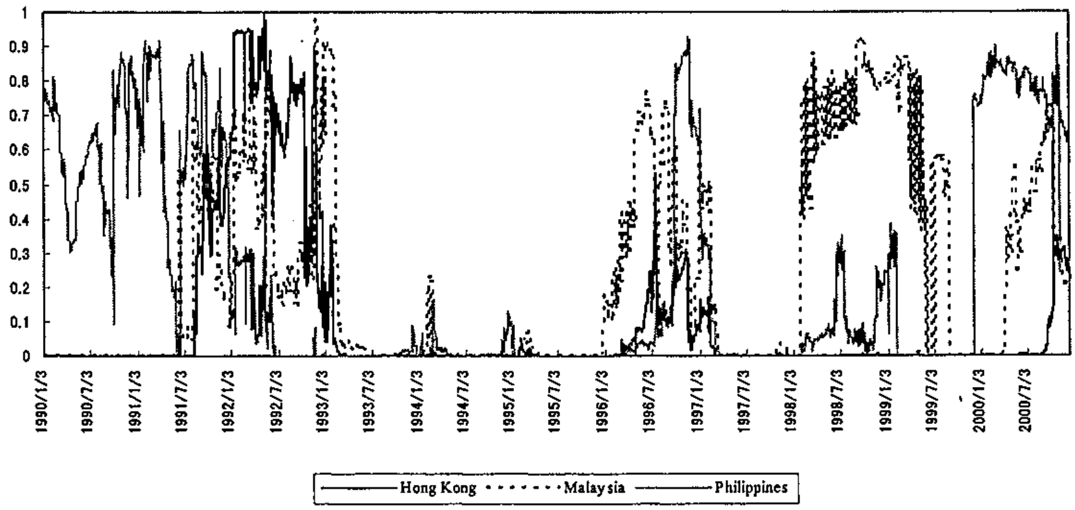
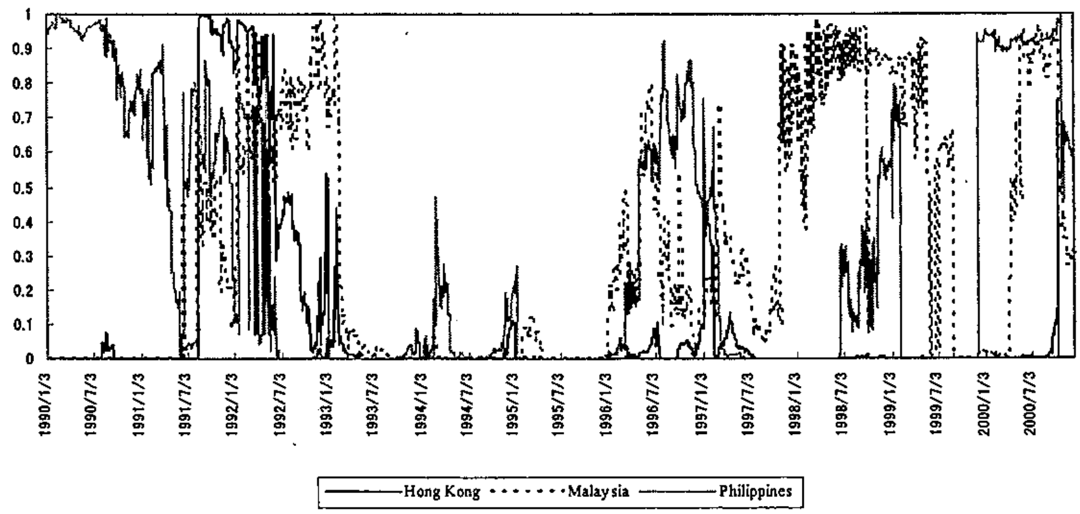


Figure 2.D
Causality in Variance to Thailand



Notes on Figure 2: The significance of the cross-correlation function test statistics for causality in mean/variance within Asia is plotted as time series. Figures 2.A and 2.B plot the p-values of the test statistic, defined by (5) in the main text, for causality in mean from and to Thailand, respectively. Similarly, Figures 2.C and 2.D chart the p-values of the test statistic, defined by (6), for causality in variance from and to Thailand, respectively. The labels on the horizontal axis denote the beginning dates of the 240-trading-day window, for which the test statistics are calculated.

Figure 3.A
Causality in Mean from Mexico

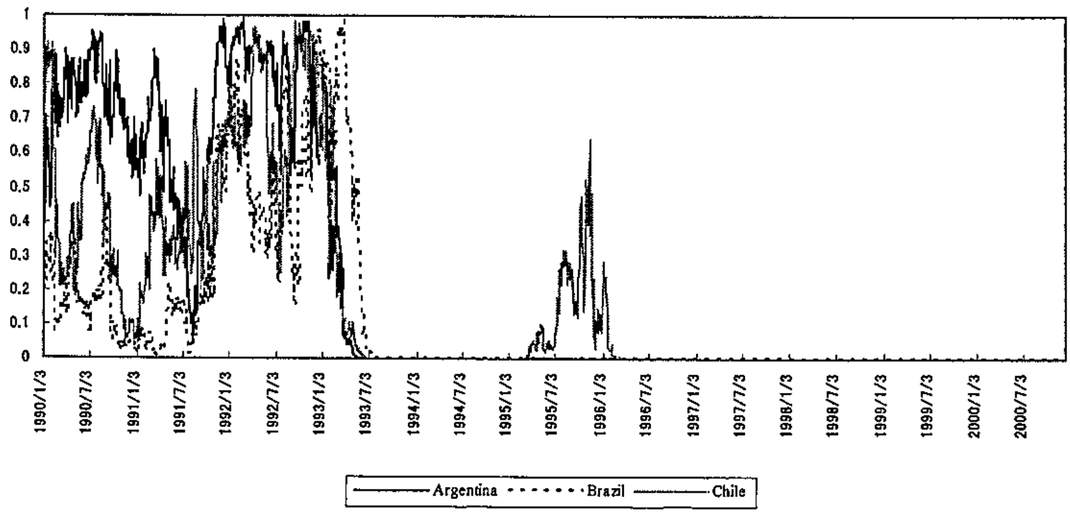


Figure 3.B
Causality in Mean to Mexico

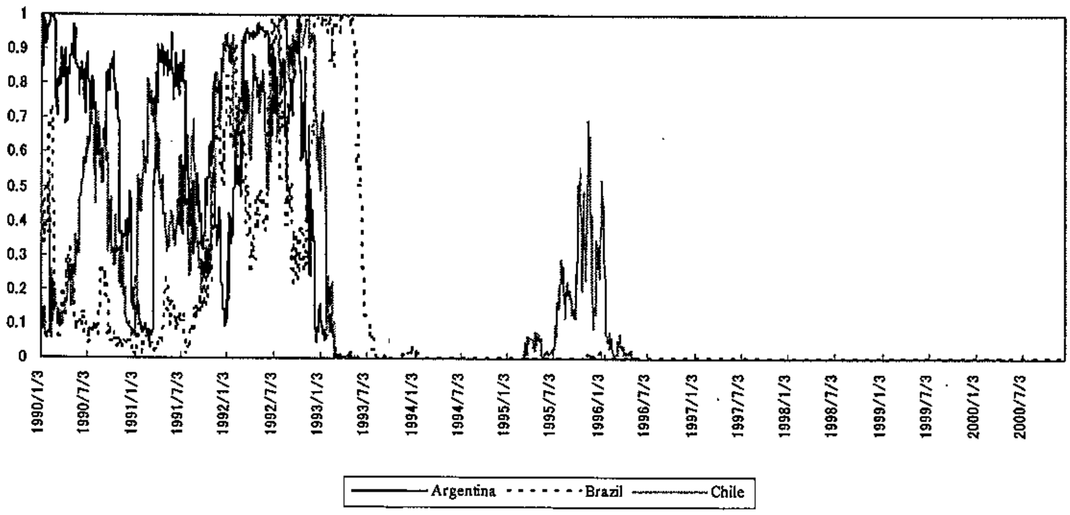


Figure 3.C
Causality in Variance from Mexico

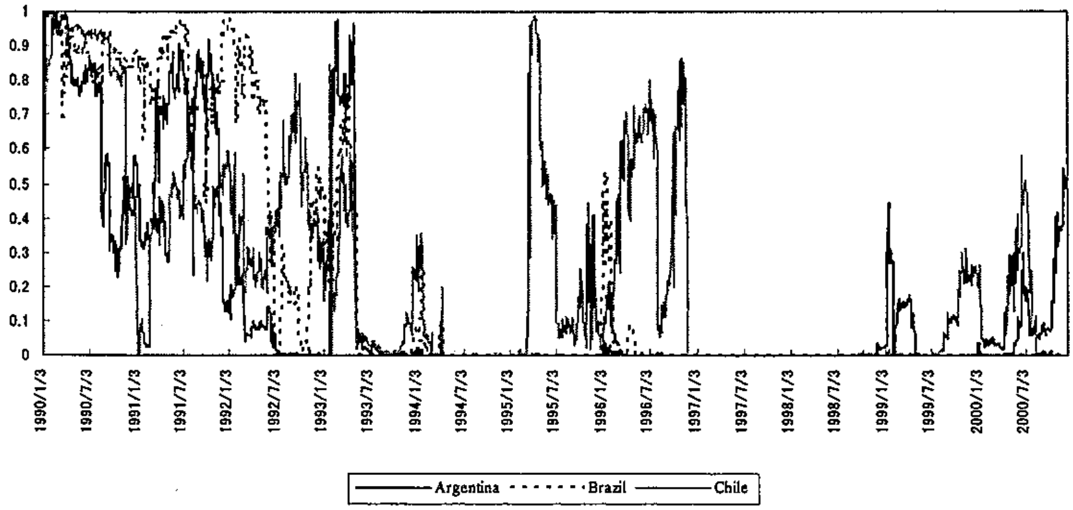
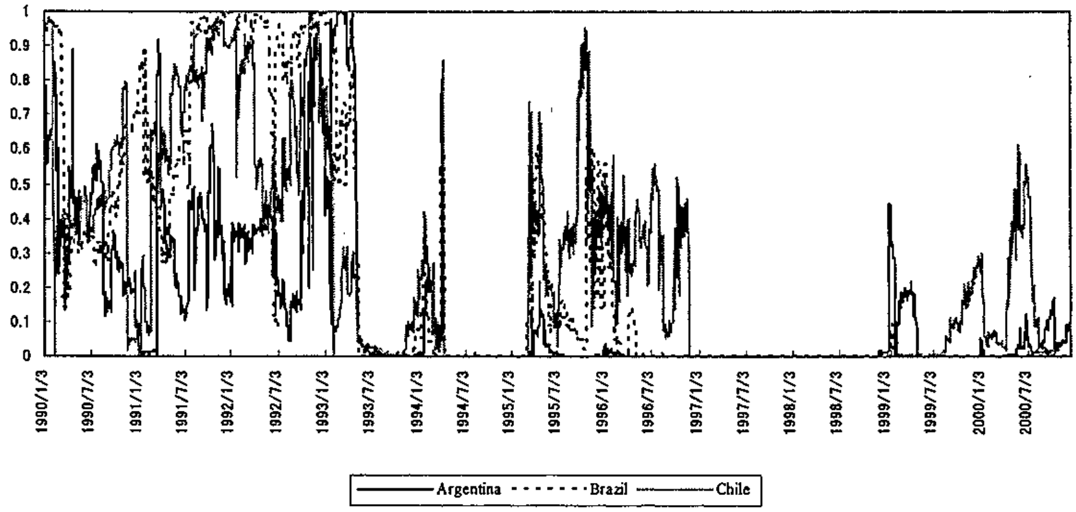


Figure 3.D
Causality in Variance to Mexico



Notes on Figure 3: The significance of the cross-correlation function test statistics for causality in mean/variance within Latin America is plotted as time series. Figures 3.A and 3.B plot the p-values of the test statistic, defined by (5) in the main text, for causality in mean from and to Mexico, respectively. Similarly, Figures 3.C and 3.D chart the p-values of the test statistic, defined by (6), for causality in variance from and to Mexico, respectively. The labels on the horizontal axis denote the beginning dates of the 240-trading-day window, for which the test statistics are calculated.

Figure 4.A
Causality in Mean from Thailand to Latin America

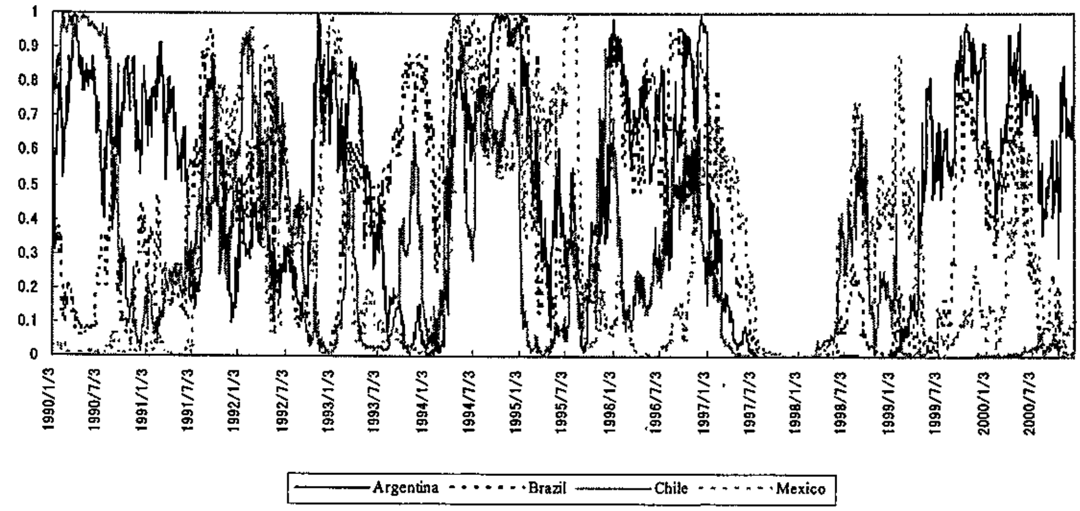
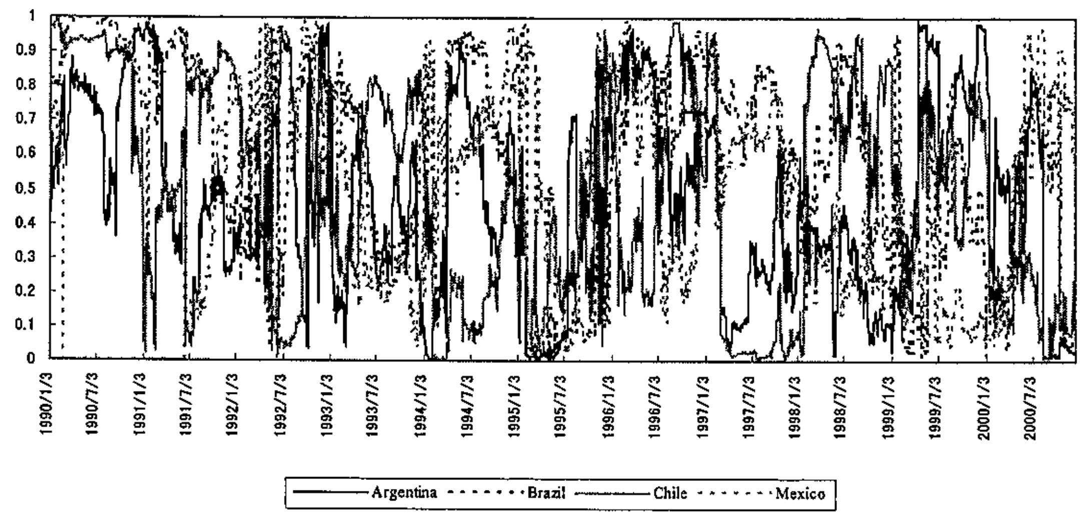


Figure 4.B
Causality in Variance from Thailand to Latin America



Notes on Figure 4: The significance of the cross-correlation function test statistics for causality in mean/variance from Asia to Latin America is plotted as time series. Figure 4.A plots the p-values of the test statistic, defined by (5) in the main text, for causality in mean from Thailand to Latin American markets. Similarly, Figure 4.B charts the p-values of the test statistic, defined by (6), for causality in variance from Thailand to Latin American markets. The labels on the horizontal axis denote the beginning dates of the 240-trading-day window, for which the test statistics are calculated.

Figure 5.A
Causality in Mean from Mexico to Asia

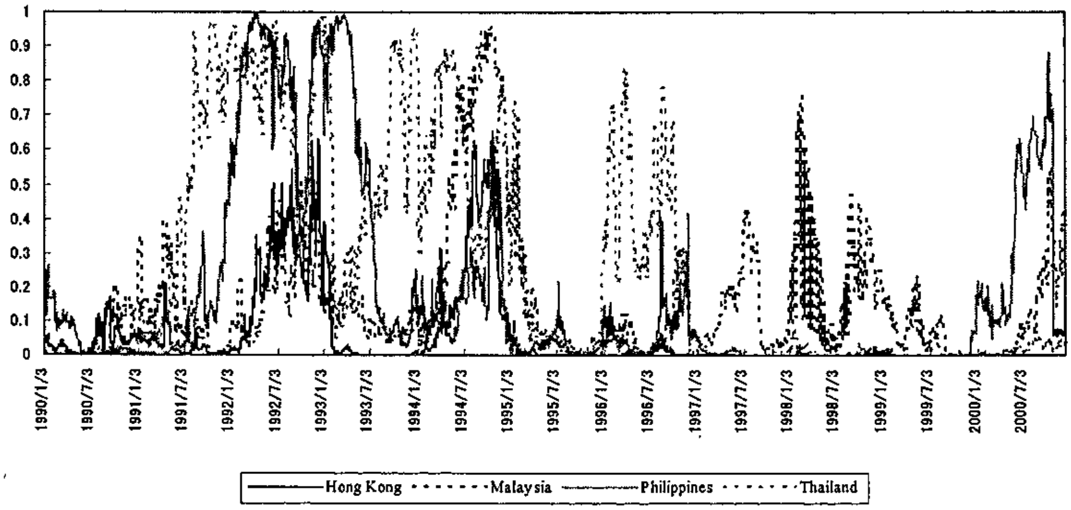
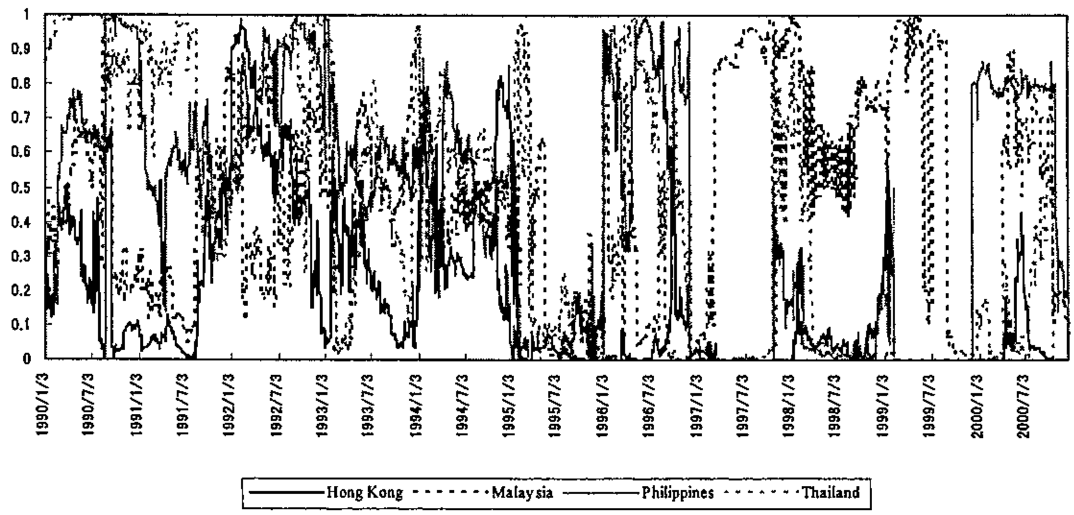


Figure 5.B
Causality in Variance form Mexico to Asia



Notes on Figure 5: The significance of the cross-correlation function test statistics for causality in mean/variance from Latin America to Asia is plotted as time series. Figure 5.A plots the p-values of the test statistic, defined by (5) in the main text, for causality in mean from Mexico to Asian markets. Similarly, Figure 5.B charts the p-values of the test statistic, defined by (6), for causality in variance from Mexico to Asian markets. The labels on the horizontal axis denote the beginning dates of the 240-trading-day window, for which the test statistics are calculated.