No Contagion, Only Interdependence: Measuring Stock Market Co-movements[1]

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Abstract

This paper tests for stock market contagion during recent financial crises. It defines contagion as a significant increase in market co-movement after a shock to one country (or group of countries). Previous work based on the correlation coefficient has found strong evidence of this type of contagion during recent financial crises. We show, however, that these tests are biased because the unadjusted cross-market correlation coefficient is conditional on market volatility. It is possible to correct for this bias, and when we make this adjustment, there is virtually no evidence of contagion during the 1997 East Asian crisis, the 1994 Mexican peso collapse, and the 1987 U.S. stock market crash. There is still a high level of market co-movement during these crisis periods, however, which reflects a continuation of strong cross-market linkages which exist in all states of the world. In other words, during these three crises, there was no contagion, only interdependence.

JEL Classification: F30, F40, G15

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1 Introduction

In October of 1997, the Hong Kong market plummeted and then partially rebounded. As shown in Figure 1, these dramatic movements were mirrored in markets in North America, South America, Europe, and the rest of Asia. In December of 1994, the Mexican market cratered, and as shown in Figure 2, this plunge was quickly reflected in other major Latin American markets. Figure 3 shows that in October of 1987 the crash of the US market quickly affected major stock markets around the globe. These cases show that dramatic movements in one stock market can have a powerful impact on markets of very different sizes and structures throughout the world. Does this high rate of stock market co-movement during periods of market turmoil constitute contagion?

Before answering this question, it is necessary to define contagion. There is widespread disagreement about what this term entails, and this paper will utilize the narrow definition of contagion which has historically been used in this literature. This paper defines contagion as a significant increase in cross-market linkages after a shock to one country (or group of countries.)[1] Cross-market linkages can be measured by a number of different statistics, such as the correlation in asset returns, the probability of a speculative attack, or the transmission of shocks or volatility. According to this definition, if two markets show a moderate degree of co-movement during periods of stability, such as Germany and Italy, and then a shock to one market leads to a significant increase in market co-movement, this would constitute contagion. On the other hand, if two markets show a high degree of co-movement during periods of stability, even if they continue to be highly correlated after a shock to one market, this may not constitute contagion. It is only contagion if cross-market co-movement increases significantly after the shock. If the co-movement does not increase significantly, then any continued high level of market co-movement suggests strong linkages between the two economies which exist in all states of the world. This is what we call interdependence. Based on this approach, contagion implies that cross-market linkages are fundamentally different after a shock to one market, while interdependence implies no significant change in cross-market relationships during a crisis.[2]

[1] In a closely related paper, Forbes and Rigobon (1999) propose using the term "shift-contagion" instead of "contagion" in order to clarify exactly what this term entails. The term shift-contagion is sensible because it not only clarifies that contagion arises from a shift in cross-market linkages, but it also avoids taking a stance on how this shift ocurred.

[2] It is important to note that this definition of contagion is not universally accepted. Some economists argue that

Although this definition of contagion is restrictive, it has two important advantages. First, it provides a straightforward framework for testing if contagion occurs. Simply compare the correlation (or covariance) between two markets during a relatively stable period (generally measured as a historic average) with that during a period of turmoil (directly after a shock occurs). Contagion is a significant increase in the cross-market relationship during the period of turmoil. This simple and intuitive test for contagion has formed the basis of this literature. A second benefit of this definition of contagion is that it provides a straightforward method of distinguishing between alternative explanations of how shocks are transmitted across markets. As discussed in the next section, there is an extensive theoretical literature on the international propagation of shocks. Many theories assume that investors (or institutions) behave differently after a large negative shock. Other theories argue that most shocks are propagated through real linkages, such as trade. It is extremely difficult to measure these various transmission mechanisms directly. By defining contagion as a significant increase in cross-market linkages, this paper avoids having to directly measure and differentiate between these various propagation mechanisms. Moreover, tests based on this definition provide a useful method of classifying theories as those which entail either a change in propagation mechanisms after a shock versus those which are a continuation of existing mechanisms. Identifying if this type of contagion exists could therefore provide evidence for or against certain theories of transmission.

While contagion can take many forms, this paper focuses on contagion across stock markets. The first half of the paper discusses conceptual issues involved in measuring this contagion. Section 2 briefly reviews the relevant theoretical and empirical literature. Section 3 discusses the conventional technique of measuring stock market contagion and proves that the correlation coefficient central to this analysis is biased. The correlation coefficient is actually conditional on market volatility over the time period under consideration, so that during a period of turmoil when stock market volatility increases, unadjusted estimates of cross-market correlations will be biased upward. We show how to adjust the correlation coefficient to correct for this bias.

The second half of this paper applies these concepts in empirical tests for contagion during

contagion occurs whenever a shock to one country is transmitted to another country, even if there is no significant change in cross-market relationships. Others argue that it is impossible to define contagion using tests for changes in cross-market linkages. Instead, they argue that it is necessary to identify exactly how a shock is propagated across countries, and only certain types of transmission mechanisms (no matter what the magnitude) constitute contagion.

three periods of market turmoil: the 1997 East Asian crisis, the 1994 Mexican peso collapse, and the 1987 US stock market crash. Sections 4 through 6 test if average cross-market correlations increase significantly during the relevant period of turmoil. For each of the three crises, tests based on the unadjusted correlation coefficients suggest that there was contagion in several markets. When the same tests are based on the adjusted correlation coefficients, however, the incidence of contagion falls dramatically (to zero in most cases.) This suggests that high cross-market co-movements during the recent East Asian crisis, the Mexican peso collapse, and the 1987 US market crash, were a continuation of strong cross-market interdependence instead of contagion. In other words, many economies are closely linked in all states of the world, and these linkages were not significantly different during these three crisis periods. The final section of the paper summarizes these findings and discusses several caveats to these results. It also introduces the new puzzle of "excess interdependence" found in this paper.

2 The International Propagation of Shocks: Theory and Previous Evidence

As discussed above and shown in Figures 1-3, stock markets of very different structures, sizes, and geographic locations can exhibit a high degree of co-movement. Since most country risk is idiosyncratic, this high degree of co-movement suggests the existence of mechanisms through which domestic shocks are transmitted internationally. This section begins by summarizing the theoretical work on international propagation mechanisms. It then proposes a general framework through which to interpret and measure these mechanisms and discusses the difficulties inherent in testing these channels. The section closes with a brief review of previous empirical work measuring stock market co-movements and testing for contagion.

2.1 Propagation Mechanisms: The Theory

The theoretical literature on how shocks are propagated internationally is extensive. Recent work in this field is well-summarized in Claessens, Dornbusch and Park (1999). For the purpose of this paper, however, it is useful to divide this broad set of theories into two groups: crisis-contingent and non-crisis-contingent theories. Crisis-contingent theories are those which explain why transmission

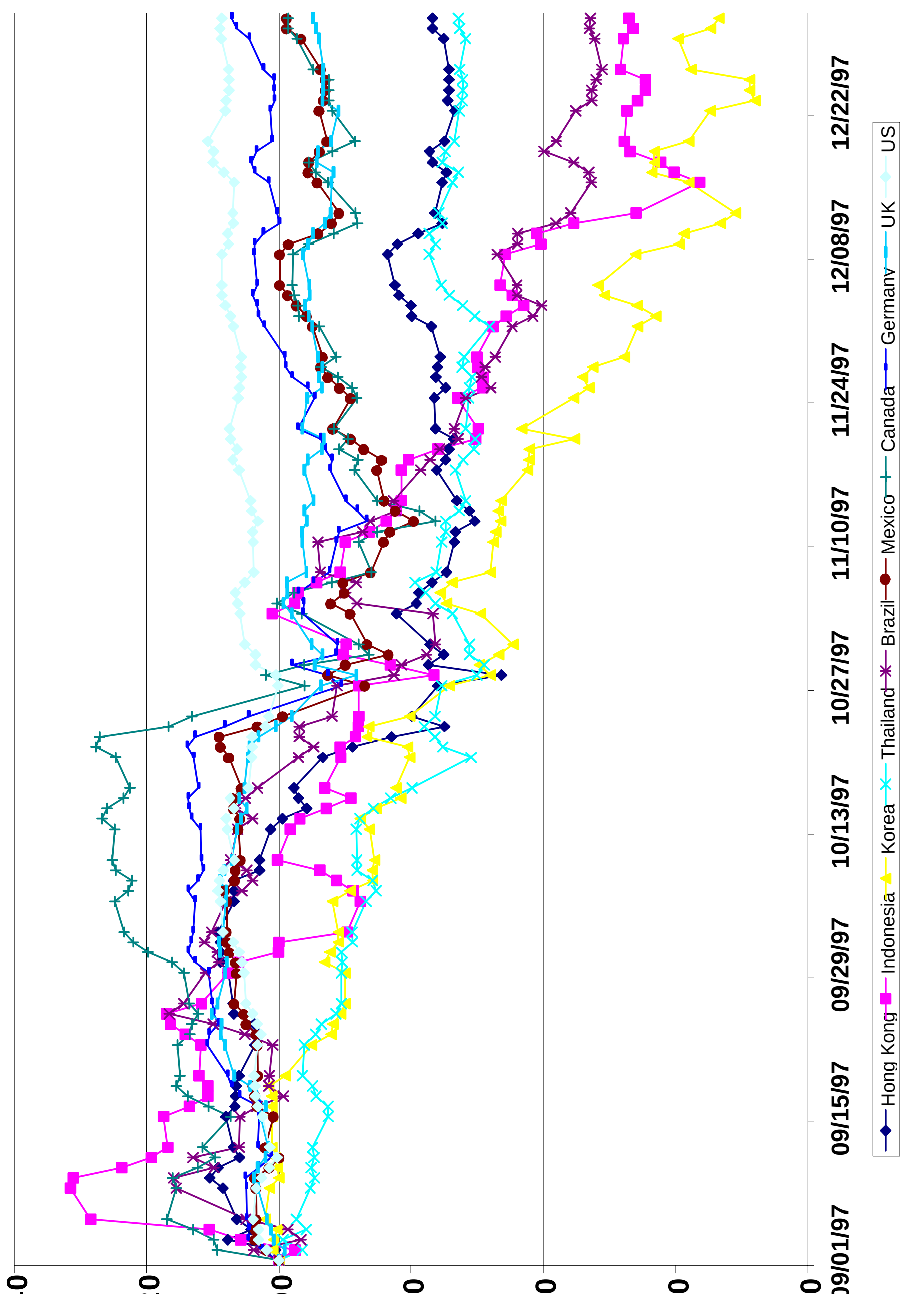

Figure 1: 1997 East Asian Crises. Stock Market Indices in US$.

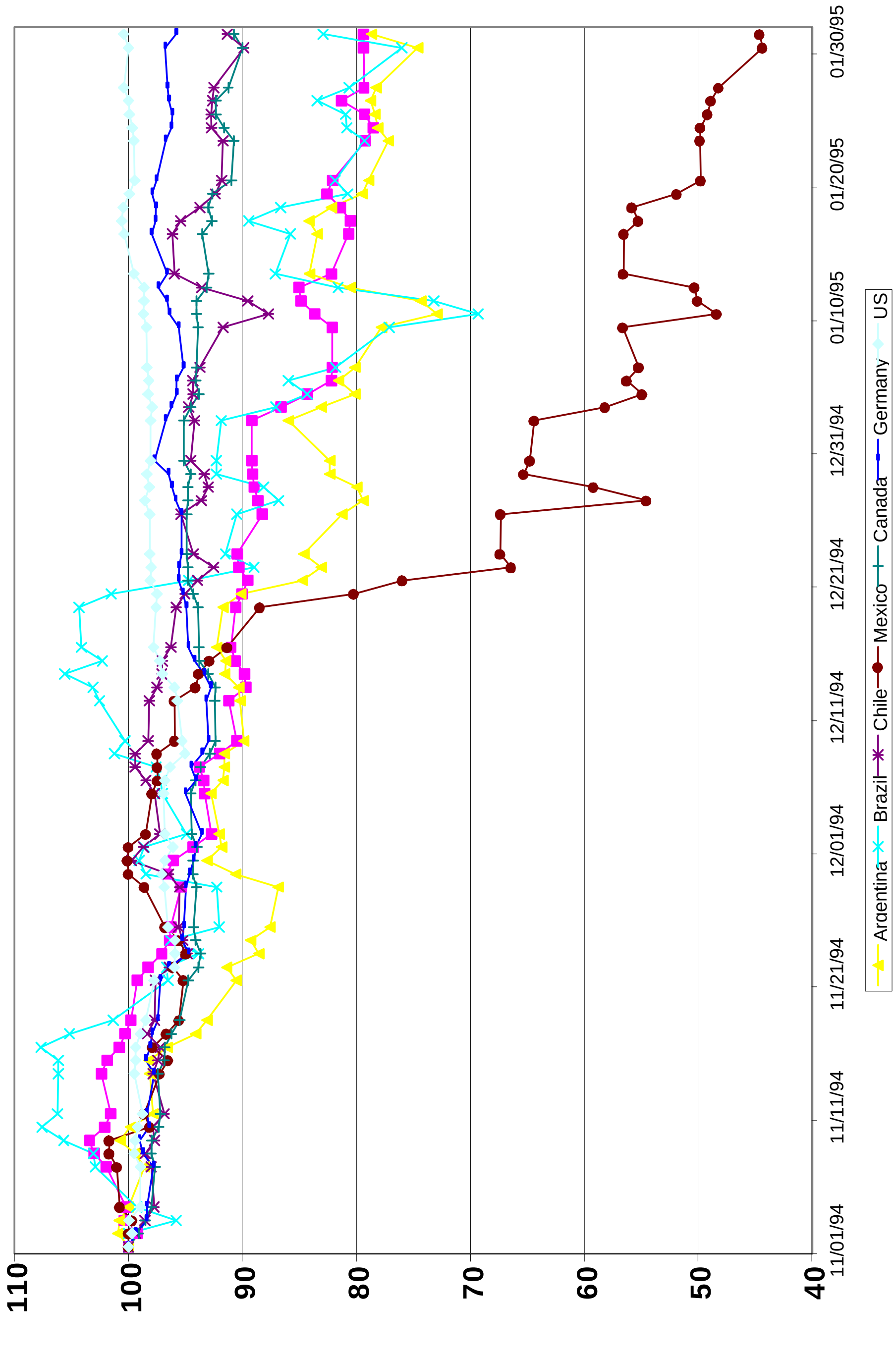

Figure 2: 1994 Mexican Peso Collapse. Stock Market Indices in US$.

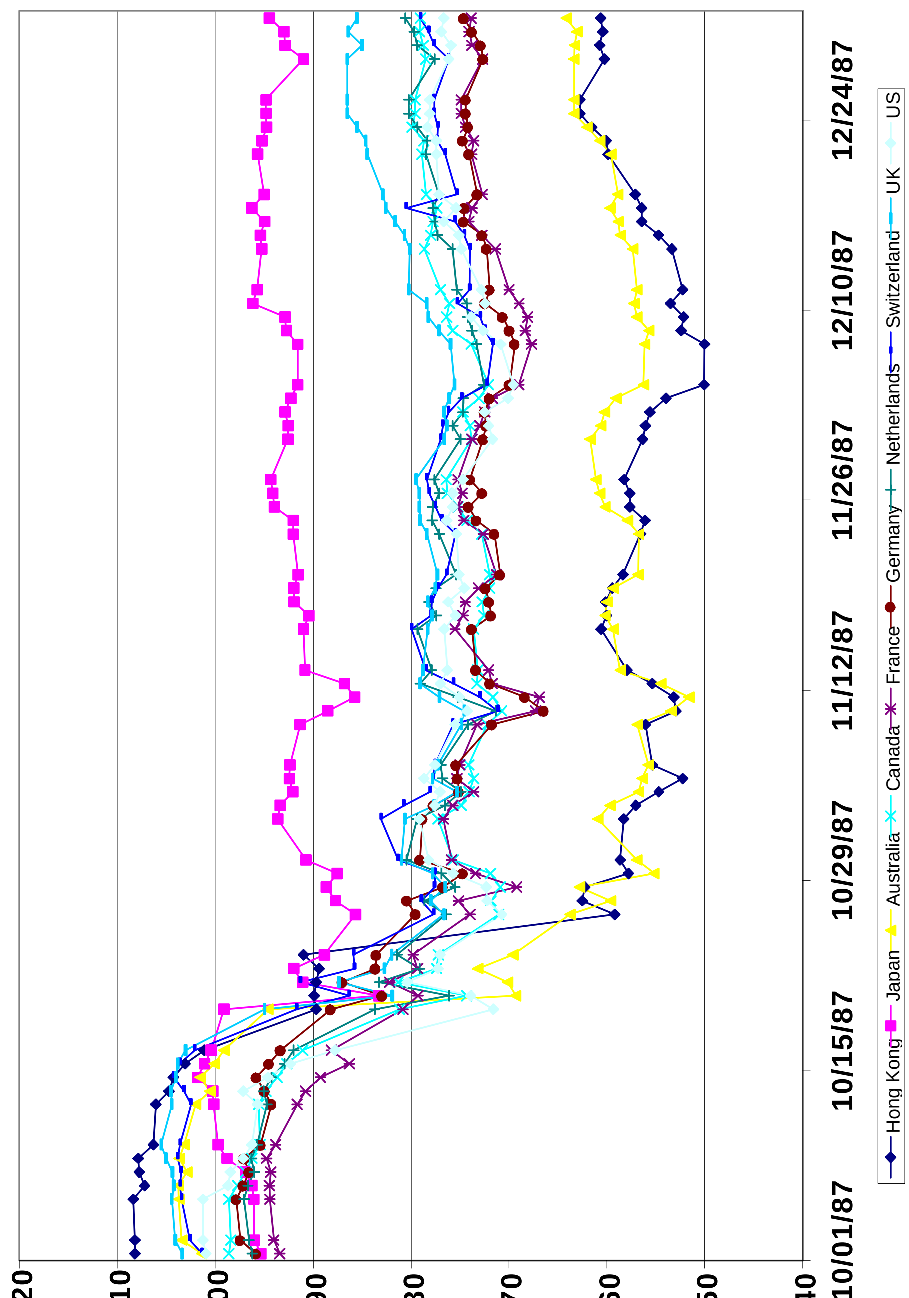

Figure 3: 1987 U.S. Stock Market Crash. Stock Market Indices in US$.

mechanisms change during a crisis and therefore why cross-market linkages increase after a shock. Non-crisis-contingent theories assume that transmission mechanisms are the same during a crisis and during more stable periods, and therefore cross-market linkages do not increase after a shock. Under our definition, contagion is explained by the crisis-contingent theories.

2.2 Crisis-Contingent Theories

Crisis-contingent theories of how shocks are transmitted internationally can be divided into three mechanisms: multiple equilibria; endogenous liquidity; and political economy. The first mechanism, multiple equilibria, occurs when a crisis in one country is used as a sunspot for other countries. For example Masson [1997] shows how a crisis in one country could coordinate investors' expectations, shifting them from a good to a bad equilibrium for another economy, and thereby cause a crash in the second economy. Mullainathan [1998] argues that investors imperfectly recall past events. A crisis in one country could trigger a memory of past crises, which would cause investors to recompute their priors (on variables such as debt default) and assign a higher probability to a bad state. The resulting downward co-movement in prices would occur because memories (instead of fundamentals) are correlated. In both of these models, the shift from a good to bad equilibrium, and the transmission of the initial shock, is therefore driven by a change in investor expectations or beliefs and not by any real linkages. This branch of theories can not only explain the bunching of crises, but also why speculative attacks occur in economies that appear to be fundamentally sound.[3] These qualify as crisis-contingent theories because the change in the price of the second market (relative to the change in the price of the first) is exacerbated during the shift between equilibria. In other words, after the crisis in the first economy, investors change their expectations and therefore transmit the shock through a propagation mechanism that does not exist during stable periods.

A second category of crisis-contingent theories is endogenous liquidity shocks. Calvo [1999] develops a model where there is asymmetric information among investors. Informed investors receive signals about the fundamentals of a country and are hit by liquidity shocks (margin calls) which may force them to sell their holdings. Uninformed investors cannot distinguish between a

[3] This point has been raised by Radelet and Sachs [1998a, 1998b], and Sachs, Tornell and Velasco [1996] for the case of Hong Kong.

liquidity shock and a bad signal, and therefore charge a premium when the informed investors are net sellers.[4] In this model, the liquidity shock increases the correlation in asset prices.[5]

A final transmission mechanism which can be categorized as a crisis-contingent theory is political contagion. Drazen [1998] studies the European devaluations in 1992-3 and develops a model which assumes that central bank presidents are under political pressure to maintain their countries' fixed exchange rates. When one country decides to abandon its peg, this reduces the political costs to other countries of abandoning their respective pegs, which increases the likelihood of these countries switching exchange rate regimes. As a result, exchange rate crises may be bunched together, and once again, transmission of the initial shock occurs through a mechanism (political economy) which did not exist before the initial crisis.

This group of crisis-contingent theories suggests a number of very different channels through which shocks could be transmitted internationally: multiple equilibria based on investor psychology; endogenous-liquidity shocks causing a portfolio recomposition; and political economy affecting exchange rate regimes. Despite the different approaches and models used to develop these theories, they all share one critical implication: the transmission mechanism in the period after the initial crisis is inherently different than that before the shock. The crisis causes a structural shift, so that shocks are propagated via a channel which does not exist in stable periods. Therefore, each of these theories could explain the existence of contagion as defined above.

2.3 Non-Crisis-Contingent Theories

On the other hand, the remainder of the theories explaining how shocks could be propagated internationally would not generate contagion (as defined in this paper) because they would not generate a change in the propagation mechanism. These theories imply that any large or small cross-market correlations after a shock are a continuation of linkages which existed before the crisis. These channels are often called "real linkages" since many (although not all) are based on economic fundamentals. These theories can be divided into four broad channels: trade; policy coordination; country reevaluation; and random aggregate shocks.

[4] See also Yuan [2000] for a formal solution to this problem.

[5] This endogenous liquidity shock is fundamentally different than an exogenous liquidity shock (which is discussed in the next section.) An endogenous liquidity shock generates a change in the propagation mechanism, while an exogenous liquidity shock does not.

The first transmission mechanism, trade, could work through several related effects.[6] If one country devalues its currency, this would have the direct effect of increasing the competitiveness of that country's goods, potentially increasing exports to a second country and hurting domestic sales within the second country. The initial devaluation could also have the indirect effect of reducing export sales from other countries which compete in the same third market. Either of these effects could not only have a direct impact on a country's sales and output, but if the loss in competitiveness is severe enough, it could increase expectations of an exchange rate devaluation and/or lead to an attack on a country's currency.

The second transmission mechanism, policy coordination, links economies because one country's response to an economic shock could force another country to follow similar policies. For example, a trade agreement might include a clause in which lax monetary policy in one country forces other member countries to raise trade barriers.

The third propagation mechanism, country reevaluation or learning (which includes models of herding and informational cascades), argues that investors may apply the lessons learned after a shock in one country to other countries with similar macroeconomic structures and policies.[7] For example, if a country with a weak banking system is discovered to be susceptible to a currency crisis, investors could reevaluate the strength of the banking system in other countries and adjust their expected probabilities of a crisis accordingly.

The final non-crisis-contingent transmission mechanism are random aggregate or global shocks which simultaneously affect the fundamentals of several economies. For example, a rise in the international interest rate, a contraction in the international supply of capital, a shift in the risk preferences of investors, or a decline in international demand (such as for commodities) could simultaneously slow growth in a number of countries.[8] Asset prices in any countries affected by this aggregate shock would move together (at least to some degree), so that directly after the shock, cross-market correlations between affected countries could increase.

[6] Gerlach and Smets [1995] first developed this theory. See Corsetti et.al. [1998] for a recent version of this theory based on microfoundations. Also see Eichengreen, Rose and Wypolsz [1996].

[7] For models of pure learning, seeRigobon [1998] and Kodres and Pritsker[1999]. For models of herding and informational cascades, see Chari & Kehoe [1999] and Calvo & Mendoza [1998].

[8] This group of theories includes exogenous liquidity shocks, such as that modelled in Valdés [1996].

2.4 Propagation Mechanisms: A Framework

The last two sections discussed a number of different mechanisms by which a shock could be transmitted internationally. These propagation mechanisms can be expressed in a simple model:

$$x_{i,t} = \alpha_i + \beta_i X_t + \gamma_i a_t + \varepsilon_{i,t} \tag{1}$$

where $x_{i,t}$ represents stock prices in country i, X_t is a vector of stock prices in countries other than i, a_t are aggregate variables which affect all countries, and $\varepsilon_{i,t}$ is an idiosyncratic shock (which is assumed to be independent of any aggregate shocks.)

In equation 1 any aggregate shocks are captured by the variable a_t, and the direct effect of these shocks on each country i is captured by the vector γ_i. Any country-specific shocks are measured by X_t (a change in stock prices in countries other than country i) and the impact of these shocks on the economic fundamentals of other countries is captured by the vector β_i. This vector β_i captures any real and/or financial linkages between different economies which exist in all states of the world and is what we call interdependence. Therefore, any non-crisis-contingent transmission channels are captured by γ_t and/or β_i. On the other hand, any crisis-contingent transmission mechanisms are captured by a change in either γ_i and/or β_i. Any such change in cross-market linkages would constitute contagion (as defined in this paper). There are a number of econometric problems with the estimation of equation 1. This has driven the empirical literature to use a variety of alternative procedures to test for contagion.

2.5 Propagation Mechanisms: Previous Empirical Work

The empirical literature testing if contagion exists is even more extensive than the theoretical literature explaining how shocks can be transmitted across markets. Much of this empirical literature uses the same definition of contagion as in this paper, although some of the more recent work has used a broader definition. Four different approaches have been utilized to test for contagion and measure how shocks are transmitted internationally: analysis of cross-market correlation coefficients; GARCH frameworks; cointegration; and probit models. Virtually all of these papers conclude that contagion–no matter how it is defined–occurred during the crisis under investigation.

Tests based on cross-market correlation coefficients are the most straightforward. These tests measure the correlation in returns between two markets during a stable period and then test for a significant increase in this correlation coefficient after a shock. If the correlation coefficient increases significantly, this suggests that the transmission mechanism between the two markets increased after the shock and contagion occurred. The majority of these papers test for contagion directly after the US stock market crash of 1987. In the first major paper on this subject, King and Wadhwani [1990] test for an increase in cross-market correlations between the US, UK, and Japan and find that correlations increase significantly after the US crash. Lee and Kim [1993] extend this analysis to twelve major markets and find further evidence of contagion: that average weekly cross-market correlations increased from 0.23 before the 1987 crash to 0.39 afterward. Calvo and Reinhart [1995] use this approach to test for contagion in stock prices and Brady bonds after the 1994 Mexican peso crisis. They find that cross-market correlations increased during the crisis for many emerging markets. To summarize, each of these tests based on cross-market correlation coefficients reaches the same general conclusion: cross-market correlation coefficients often increase significantly during the relevant crisis, and therefore contagion occurred during the period under investigation.[9]

A second approach to testing for contagion is to use an ARCH or GARCH framework to estimate the variance-covariance transmission mechanism across countries. Chou et. al. [1994] and Hamao et. al. [1990] use this procedure and find evidence of significant spill-overs across markets after the 1987 US stock market crash. They also conclude that contagion does not occur evenly across countries, but that it is fairly stable through time. Edwards [1998] examines the propagation across bond markets after the Mexican peso crisis, with a focus on how capital controls affect the transmission of shocks. He estimates an augmented GARCH model and shows that there were significant spill-overs from Mexico to Argentina, but not from Mexico to Chile. His tests indicate that volatility was transmitted from one country to the other, but they do not indicate if this propagation mechanism changed during the crisis.

A third series of tests for contagion focus on changes in the long-run relationship between markets instead of on any short-run changes after a shock. These papers use the same basic

[9] For further applications of this procedure see: Bertero & Mayer [1990] for a study of why the transmission of the US stock market crash differed across countries; Karolyi & Stulz [1996] for an analysis of comovements between the US and Japanese markets; Pindyck & Rotemberg [1993] for a study of comovements in individual stock prices within the US; Pindyck & Rotemberg [1990] for an analysis of commovements in commodity prices; and Masson [1997] for an application to speculative attacks.

procedures as above, except test for changes in the co-integrating vector between stock markets instead of in the variance-covariance matrix. For example, Longin & Slonik [1995] consider seven OECD countries from 1960 to 1990 and report that average correlations in stock market returns between the US. and other countries rose by about 0.36 over this period.[10] This approach is not an accurate test for our definition of contagion, however, since it assumes that real linkages between markets (i.e. the non-crisis-contingent theories such as trade flows) remain constant over the entire period. If tests show that the co-integrating relationship increased over time, this could be a permanent shift in cross-market linkages instead of contagion. Moreover, by focusing on such long time periods, this set of tests could miss brief periods of contagion (such as after the Russian collapse of 1998).

Instead of testing for changes in correlation coefficients, variance matrices, or cointegrating relationships, the final approach to testing for contagion uses simplifying assumptions and exogenous events to identify a model and directly measure changes in the propagation mechanism. Baig and Goldfajn [1998] study the impact of daily news (the exogenous event) in one country's stock market on other countries markets during the 1997-98 East Asian crisis. They find that a substantial proportion of a country's news impacts neighboring economies. Forbes [1999] estimates the impact of the Asian and Russian crises on stock returns for individual companies around the world. She finds that country-specific effects and trade (which she divides into competitiveness and income effects) are all important transmission mechanisms. Eichengreen, Rose and Wyplosz [1996] and Kaminsky and Reinhart [1998] estimate probit models to test how a crisis in one country (the exogenous event) affects the probability of a crisis occurring in other countries. Eichengreen, Rose and Wyplosz [1996] examine the ERM countries in 1992-3 and find that the probability of a country suffering a speculative attack increases when another country in the ERM is under attack. They also argue that the initial shock is propagated primarily through trade.[11] Kaminsky and Reinhart [1998] estimate the conditional probability that a crisis will occur in a given country and find that this probability increases when more crises are occurring in other countries (especially in the same region).

To summarize, a variety of different econometric techniques have been used to test if contagion

[10] For further examples of tests based in co-integration, see Cashin et al. [1995] or Chou et al. [1994].

[11] Glick and Rose [1998] use a different framework to investigate five crisis periods and agree that trade linkages play an important role in the transmission of shocks.

occurred during a number of financial and currency crises. The transmission of shocks has been measured by simple cross-market correlation coefficients, GARCH models, cointegration techniques, and probit models. The cointegration analysis is not an accurate test for contagion due to the long time periods under consideration. Results based on the other techniques, however, all arrive at the same general conclusion: some contagion occurred. The consistency of this finding is remarkable given the range of techniques utilized and periods investigated.

3 Measuring Contagion

3.1 Bias in the Correlation Coefficient

While these empirical tests for contagion have utilized a number of different methodologies and procedures, the remainder of this paper will focus on tests using correlation coefficients and discuss problems that can arise from these tests. More specifically, this section shows that heteroscedasticity biases the unadjusted correlation coefficient, and this bias is especially large during the periods of market turmoil. This discussion builds on Ronn [1998], which addresses this bias in the estimation of intra-market correlations in stocks and bonds.[12] Ronn, however, utilizes more restrictive assumptions to prove this bias and does not apply this issue to the measurement of cross-market correlations or to any form of contagion. For simplicity, in the discussion below we focus on the intuition behind this bias in the two market case.[13] Appendix A presents a more formal proof.

Assume x and y are stochastic variables which represent stock market returns (in two different markets) and these returns are related according to the equation:

$$y_t = \alpha + \beta x_t + \varepsilon_t \tag{2}$$

where $E[\varepsilon_t] = 0$, $E\left[\varepsilon_t^2\right] < \infty$, and $E[x_t \varepsilon_t] = 0$. Note that it is not necessary to make any further assumptions about the distribution of the residuals. Also, for the purpose of this discussion, assume that $|\beta| < 1$.(The appendix shows that this assumption may be dropped.) Then divide the sample

[12] Ronn [1998] indicates that this result was first proposed by Rob Stambaugh in a discussion of the Karolyi and Stulz [1995] paper at the May NBER Conference on Financial Risk Assessment and Management.

[13] For an even more intuitive discussion of how heteroscedasticity affects tests for contagion, see Forbes and Rigobon [1999]. They develop a number of coin-tossing examples to clarify this point.

into two sets, so that the variance of x_t is lower in one group (l) and higher in the second group (h.) In terms of the previous discussion, the low-variance group is the period of relative market stability and the high-variance group is the period of market turmoil.

Next, since $E[x_t \varepsilon_t] = 0$ by assumption, OLS estimates of equation 2 are consistent and efficient for both groups and $\beta^h = \beta^l$. By construction we know that $\sigma_{xx}^h > \sigma_{xx}^l$, which when combined with the standard definition of β:

$$\beta^h = \frac{\sigma_{xy}^h}{\sigma_{xx}^h} = \frac{\sigma_{xy}^l}{\sigma_{xx}^l} = \beta^l \tag{3}$$

implies that $\sigma_{xy}^h > \sigma_{xy}^l$. In other words, the cross-market covariance is higher in the second group, and this increase in the cross-market covariance from that in the first group is directly proportional to the increase in the variance of x.

Meanwhile, according to 2, the variance of y is:

$$\sigma_{yy} = \beta^2 \sigma_{xx} + \sigma_{ee}$$

Since the variance of the residual is constant and $|\beta| < 1$, the increase in the variance of y across groups is less than proportional to the increase in the variance of x. Therefore,

$$\left(\frac{\sigma_{xx}}{\sigma_{yy}}\right)^h > \left(\frac{\sigma_{xx}}{\sigma_{yy}}\right)^l \tag{4}$$

Finally, substitute 3 into the standard definition of the correlation coefficient:

$$\rho = \frac{\sigma_{xy}}{\sigma_x \sigma_y} = \beta \frac{\sigma_x}{\sigma_y}$$

and when combined with 4, this implies that $\rho^h > \rho^l$.

As a result, the estimated correlation between x and y will increase when the variance of x increases–even if the true relationship (β) between x and y does not change. Therefore, inference about the change of the propagation mechanism based on the correlation coefficient can be misleading; the unadjusted correlation coefficient is conditional on the variance of x.

The formal proof presented in Appendix A shows that it is possible to quantify this bias under certain conditions. Specifically, in the absence of endogeneity and omitted variables the conditional correlation can be written as:

$$\rho^u = \rho \sqrt{\frac{1+\delta}{1+\delta\rho^2}} \tag{5}$$

where ρ^u is the unadjusted (or conditional) correlation coefficient, ρ is the actual (or unconditional) correlation coefficient, and δ is the relative increase in the variance of x:

$$\delta \equiv \frac{\sigma_{xx}^h}{\sigma_{xx}^l} - 1$$

Equation 5 clearly shows that the estimated correlation coefficient increases in δ. Therefore, during periods of high volatility in market x, the estimated correlation between markets y and x will be greater than the actual correlation. As a result, estimated correlation coefficients will be biased upward during periods of market turmoil. Since markets tend to be more volatile after a shock, this could lead us to incorrectly accept that cross-market correlations increase after a crisis. This bias alone could generate the finding of contagion reported in the studies discussed above.

It is straightforward to adjust for this bias. Simple manipulation of equation 5 to solve for the unconditional correlation yields:

$$\rho = \frac{\rho^u}{\sqrt{1+\delta\left[1-(\rho^u)^2\right]}} \tag{6}$$

One potential problem with this adjustment for heteroscedasticity is that it may not be valid in the presence of endogeneity and/or omitted variables. In fact, the proof of this bias assumes that there is no feedback from stock market y to x and that there are no exogenous global shocks (i.e. that $a = 0$ in equation 1.) The adjustment, however, is a relatively good approximation in the presence of endogeneity and omitted variables if the change in the variance is large and it is possible to identify the country where the shock originated. The intuition behind why the adjustment is still a good approximation in these circumstances is based on what the simultaneous-equations literature calls near identification. More specifically, assume that there are two countries whose returns are simultaneously determined and both affected by an aggregate shock. If it is known that a shock is produced in one of the countries at a certain time, then the increase in the correlation is caused almost fully by the idiosyncratic shock and not by the aggregate shock.

In the empirical implementation below, we utilize these criteria for near-identification when deciding which pairs of correlations to calculate and test for contagion. The three criteria are: a major shift in market volatility; identifying which country generates this shift; and including this crisis country in the estimated correlation. The data suggests that these criteria are satisfied during the crisis periods investigated in this paper. During the three relevant periods, the variance of returns in the crisis countries increased by over 10 times, and the source of the shock is clear (Hong Kong in 1997, Mexico in 1994, and the US in 1987.) We only report and test for contagion from the country where the shock originated to the other countries in the sample. For example, during the Mexican crisis a large increase in market volatility was caused by events in Mexico, and it is only valid to analyze cross-market correlations between Mexico and each of the other countries in the sample.

To clarify the intuition and relevance of this adjustment for heteroscedasticity, Figure 4 graphs the correlation in stock market returns between Hong Kong and the Philippines during 1997.[14] The dashed line is the unadjusted correlation in daily returns (ρ_t^u), and the solid line is the adjusted correlation (ρ_t). While the two lines tend to move up and down together, the bias generated by heteroscedasticity is clearly significant. During the relatively stable period in the first half of 1997, the unadjusted correlation is always lower than the adjusted correlation. On the other hand, during the relatively tumultuous period of the fourth quarter, the unadjusted correlation is significantly greater than the adjusted correlation. Tests based on the unadjusted correlations would find a significant increase in cross-market correlations in the fourth quarter and would therefore indicate contagion. On the other hand, the adjusted correlations do not increase by nearly as much, so an analysis based on these unconditional correlations might not suggest contagion.

To summarize, most tests for contagion examine if cross-market correlations increase after a

[14] Correlations are calculated as quarterly moving averages. The exact procedure, definitions, and data source used to estimate this graph are described in more detail below.

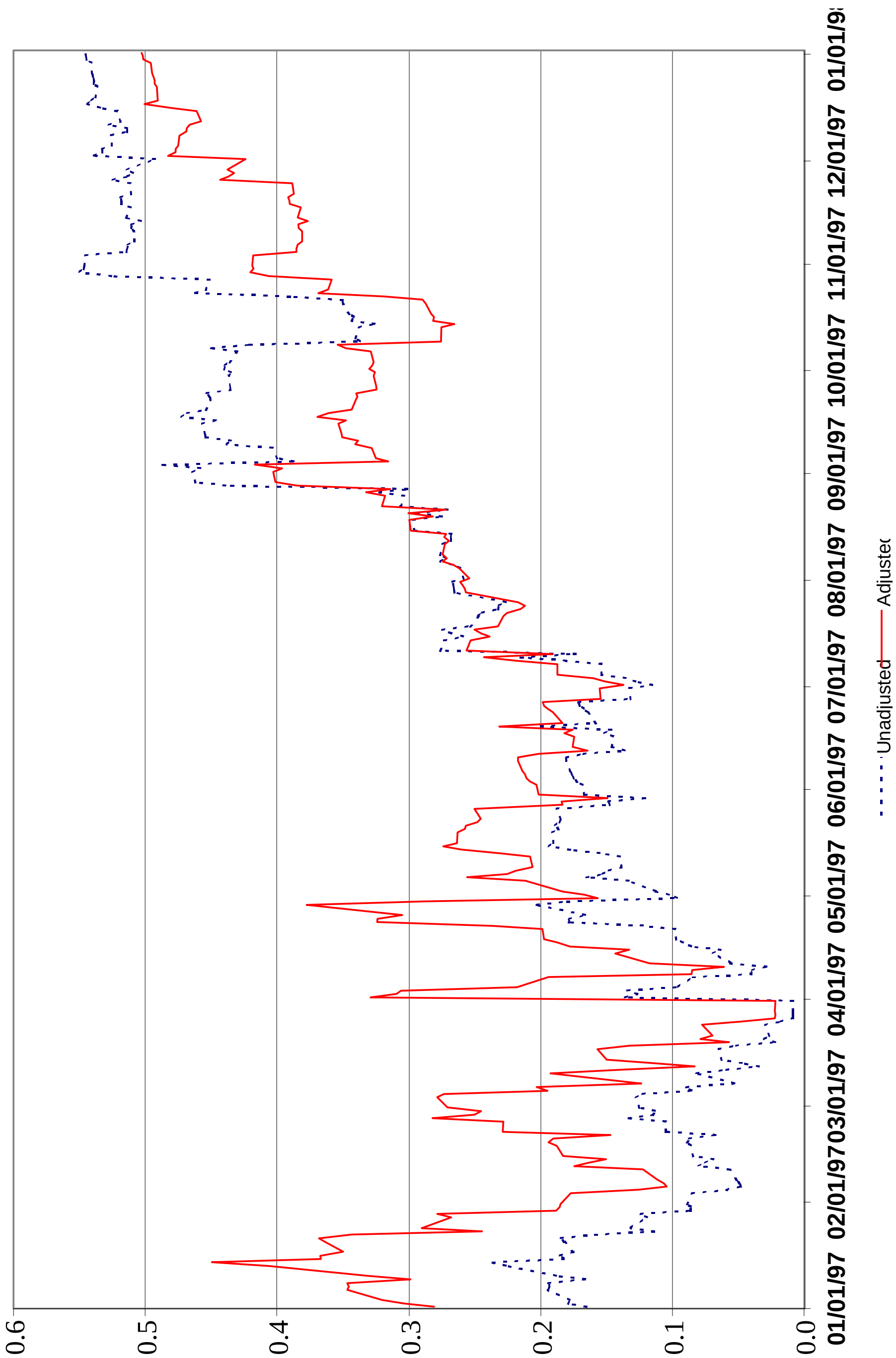

Figure 4: Cross-Market Correlations: Hong Kong and the Philippines.

shock. Since the correlation coefficient central to this analysis is biased upward during periods of market turmoil, estimated correlation coefficients will increase–even though actual correlations may remain relatively constant. This could incorrectly lead to the conclusion that contagion occurs. The remainder of this paper examines if this bias from heteroscedasticity has a significant impact on estimates of cross-market correlations and tests for contagion during the 1997 East Asian crisis, the 1994 Mexican peso collapse, and the 1987 US stock market crash.

3.2 The Data and Sample

Before performing these tests for contagion, it is necessary to briefly discuss our data and sample. To calculate stock market returns, we utilize daily values of aggregate stock market indices reported by Datastream. We perform each analysis using market returns measured in US dollars and in local currency, and in most cases, the currency unit does not affect our central findings. Since US dollar returns are used more frequently in previous work on contagion, and also to avoid an unnecessary repetition of results, we focus on estimates based on US dollars in the discussion below. (We continue to report estimates based on local returns if results are significantly different.) Moreover, US dollar returns have the additional advantage of controlling for inflation (under non-fixed exchange rate regimes).

Next, given this data set, it is necessary to choose which markets on which to focus. Most of the work discussed in Section 2 examines a small sample of countries-often just the three largest markets or stock markets in industrial countries. This was a logical choice for the time period many of these papers covered (around 1987), because stock markets in most emerging economies were small and restricted-if they even existed at all. With such a limited sample, however, it is obviously difficult to draw any conclusions about contagion within emerging markets or between developed economies and emerging markets. Since we would like to investigate each of these forms of contagion, and especially since the liquidity of many emerging markets has increased over the past few years, this paper substantially augments earlier samples. It considers the relative movements of twenty-eight markets: the twenty-four largest markets (as ranked by market capitalization at the end of 1996), plus the Philippines (to expand coverage of East Asia), Argentina and Chile (to expand coverage of Latin America), and Russia (to expand coverage of emerging markets outside of these two regions.)

Table 1 lists these countries with total stock market capitalizations and average market volumes.[15] It also defines the regions utilized throughout this paper.

Region	Country	Market Cap. (Bn US$)	Value Traded (Bn US$)
East Asia	Hong Kong	449.4	166.4
	Indonesia	91.0	32.1
	Japan	3088.9	1251.9
	Korea	138.9	177.3
	Malaysia	307.2	173.6
	Philippines	80.6	25.5
	Singapore	150.2	42.7
	Taiwan	273.6	470.2
	Thailand	99.8	44.4
Latin America	Argentina	44.7	-
	Brazil	262.0	112.1
	Chile	65.9	8.5
	Mexico	106.5	43.0
OECD	Australia	311.9	145.5
	Belgium	119.8	26.1
	Canada	486.3	265.4
	France	591.1	277.1
	Germany	670.9	768.7
	Italy	258.2	102.4
	Netherlands	378.7	339.5
	Spain	242.8	249.1
	Sweden	247.2	136.9
	Switzerland	402.1	392.8
	UK	1740.3	578.5
	US	8484.4	7121.5
Other Emerging Markets	India	122.6	109.5
	Russia	37.2	-
	South Africa	241.6	27.2

Table 1: Stock Market Characteristics

4 Contagion During the 1997 East Asian Crisis

As our first analysis of the impact of bias in the correlation coefficient, we test for contagion during the East Asian crisis of 1997. As shown in Figure 1, stock market values in East Asia fluctuated wildly in the later half of 1997, and many of these movements were mirrored, to varying degrees, in stock markets around the world. One difficulty in testing for contagion during this period is that there is no single event which acts as a clear catalyst behind this turmoil. For example, during June the Thai market plummeted, during August the Indonesian market cratered, and in mid-October

[15] Source: International Finance Corporation. Emerging Stock Market Factbook. 1997.

the Hong Kong market crashed. A review of American and British newspapers and periodicals during this period, however, shows an interesting pattern. The press paid little attention to the earlier movements in the Thai and Indonesian markets (and, in fact, paid little attention to any movements in East Asia) until the mid-October crash in Hong Kong. After the Hong Kong crash, events in Asia became headline news, and an avid discussion quickly began on the East Asian "crisis" and the possibility of "contagion" to the rest of the world. Therefore, for our base analysis in this section, we focus on tests for contagion from Hong Kong to the rest of the world during the tumultuous period directly after the Hong Kong crash. It is obviously possible that contagion occurred during other periods of time, or from the combined impact of turmoil in a group of East Asian markets instead of a single country. We test for these various types of contagion in the sensitivity analysis below and show that using these different sources of contagion has no significant impact on key results.

Using the October crash of the Hong Kong market as the most likely event to drive contagion, we define our period of turmoil as the one month starting on October 17, 1997 (the start of this visible Hong Kong crash). We define the period of relative stability as lasting from January 1, 1996 to the start of the period of turmoil.[16] While this choice of dates may appear capricious, the extensive robustness tests performed below will show that period definition does not affect the central results. Next, the specification which we estimate is:

$$X_t = \phi(L)X_t + \Phi(L)I_t + \eta_t \quad (7)$$

$$X_t \equiv \left\{x_t^{HK}, x_t^j\right\}'$$

$$I_t \equiv \left\{i_t^{HK}, i_t^{US}, i_t^j\right\}' \quad (8)$$

where x_t^{HK} is the rolling-average, two-day return in the Hong Kong market, x_t^j is the rolling-average, two-day return in market j, X_t is the correlation between these two markets, $\phi(L)$ and $\Phi(L)$ are vectors of lags, $i_t^{HK}, i_t^{US}, i_t^j$ are short-term interest rates for Hong Kong, the US and country j, respectively, and η_t is a vector of reduced-form disturbances. We utilize average two-day returns

[16] We do not utilize a longer length of time for the stability period due to the fact that any structural change in markets over this period would invalidate our test for contagion.

to control for the fact that markets in different countries are not open during the same hours. For example, Latin American markets were closed at the time of the Hong Kong crash, so any impact on Latin America would be reflected in market returns for the following day. The robustness tests reported below show that the use of daily or weekly returns will not affect the central results. We utilize five lags for $\phi(L)$ and $\Phi(L)$ in order to control for any within-week variation in trading patterns. As also shown below, the number of lags does not significantly affect results. We include interest rates in this equation in order to control for any aggregate shocks and/or monetary policy coordination (as discussed in Section 2.) Although interest rates are an imperfect measure of aggregate shocks, they are a good proxy for global shifts in real economic variables and/or policies which affect stock market performance. We also show that excluding interest rates, or including different combinations of interest rates, will not impact our central results.

Using this specification, we perform the standard test for stock market contagion described in Section 2. We estimate the variance-covariance matrices during the period of turmoil and the full period (including both the periods of relative stability and turmoil), and then use these matrices to calculate correlations between Hong Kong and each of the other markets in our sample. We use the asymptotic distribution of the standard, unadjusted correlation coefficient and do not adjust this coefficient to account for the bias introduced by heteroscedasticity. Finally, we use a $\mathtt{t}$-test to evaluate if there is a significant increase in these correlation coefficients during the period of turmoil.[17] If ρ is the correlation during the full period and $\rho_{\mathtt{t}}^{\mathtt{h}}$ is the correlation during the turmoil period, the test hypotheses are:

$$\begin{aligned} H_{\mathtt{0}} &: \rho \geq \rho_{\mathtt{t}}^{\mathtt{h}} \\ H_{\mathtt{1}} &: \rho < \rho_{\mathtt{t}}^{\mathtt{h}} \end{aligned}$$

The estimated, unadjusted correlation coefficients for the period of stability, period of turmoil, and full period are shown in Table 2. The critical value for the t-test at the 5% level is 1.65, so any test statistic greater than this critical value indicates contagion (C), while any statistic less than this value indicates no contagion (N). Test statistics and results are also reported in the table.

[17] We have also experimented with a number of other tests, and in each case, the test specification has no significant impact on results.

Region	Country	Stability ρ	Stability σ	Turmoil ρ	Turmoil σ	Full Period ρ	Full Period σ	Test Stat.	Contag?
East Asia	Indonesia	0.381	0.040	0.749	0.146	0.428	0.037	1.75	C
	Japan	0.231	0.044	0.559	0.229	0.263	0.042	1.09	N
	Korea	0.092	0.046	0.683	0.178	0.173	0.044	2.30	C
	Malaysia	0.280	0.043	0.465	0.261	0.288	0.041	0.58	N
	Philippines	0.294	0.042	0.705	0.168	0.323	0.041	1.83	C
	Singapore	0.341	0.041	0.493	0.252	0.348	0.040	0.50	N
	Taiwan	0.010	0.046	0.149	0.326	0.028	0.046	0.33	N
	Thailand	0.046	0.046	0.402	0.279	0.082	0.045	0.99	N
Latin America	Argentina	0.030	0.046	-0.144	0.326	0.004	0.046	-0.40	N
	Brazil	0.105	0.046	-0.593	0.332	0.080	0.045	-0.37	N
	Chile	0.144	0.045	0.619	0.206	0.197	0.044	1.69	C
	Mexico	0.238	0.044	0.241	0.314	0.238	0.043	0.01	N
OECD	Australia	0.356	0.040	0.865	0.084	0.431	0.037	3.59	C
	Belgium	0.140	0.045	0.714	0.163	0.178	0.044	2.58	C
	Canada	0.145	0.045	0.378	0.286	0.170	0.044	0.63	N
	France	0.227	0.044	0.886	0.072	0.299	0.042	5.19	C
	Germany	0.383	0.039	0.902	0.062	0.450	0.036	4.60	C
	Italy	0.175	0.045	0.896	0.066	0.236	0.043	6.05	C
	Netherlands	0.319	0.042	0.742	0.150	0.347	0.040	2.08	C
	Spain	0.191	0.045	0.878	0.076	0.269	0.042	5.14	C
	Sweden	0.233	0.044	0.796	0.122	0.298	0.042	3.04	C
	Switzerland	0.183	0.045	0.842	0.097	0.232	0.043	4.34	C
	UK	0.255	0.043	0.615	0.201	0.280	0.042	1.34	N
	US	0.021	0.046	-0.390	0.285	-0.027	0.046	-1.11	N
Other Emerging Markets	India	0.097	0.046	0.024	0.333	0.089	0.045	-0.17	N
	Russia	0.026	0.043	0.866	0.084	0.365	0.040	4.07	C
	S. Africa	0.368	0.040	0.852	0.092	0.455	0.036	3.10	C

Table 2: 1997 East Asian Crises: Unadjusted Correlation Coefficients

Several patterns are immediately apparent. First, cross-market correlations during the relatively stable period are not surprising. Hong Kong is highly correlated with Australia and many of the East Asian economies, and much less correlated with the Latin American markets. Second, cross-market correlations between Hong Kong and most of the other countries in the sample increase during the turmoil period. This is a prerequisite for contagion to occur. This change is especially notable in many of the OECD markets, where the average correlation with Hong Kong increases from 0.22 during the stability period to 0.68 during the turmoil period. In one extreme example, the correlation between Hong Kong and Belgium increases from 0.14 in the period of stability to 0.71 in the period of turmoil. Third, the t-tests indicate a significant increase in this unadjusted correlation coefficient during the turmoil period for fifteen countries. According to the interpretation standard in this literature, this implies contagion occurred from the October crash of the Hong Kong market to Australia, Belgium, Chile, France, Germany, Indonesia, Italy, Korea, the Netherlands, the Philippines, Russia, South Africa, Spain, Sweden, and Switzerland. As discussed above, however, these increases in the correlation coefficient might result from a bias due to heteroscedasticity and not actually constitute contagion.

To test how this bias in the correlation coefficient affects our tests for contagion, we repeat this analysis but use the correction in equation 6 to adjust for this bias. In other words, we repeat the above analysis using the unconditional instead of the conditional correlation coefficients.[18] Estimated, adjusted correlation coefficients and test results are shown in Table 3.

It is immediately apparent that adjusting for the bias from heteroscedasticity has a significant impact on estimated cross-market correlations and the resulting tests for contagion. In each country, the adjusted correlation is substantially smaller (in absolute value) than the unadjusted correlation during the turmoil period and is slightly greater in the stability period. For example, during the turmoil period, the average unadjusted correlation for the entire sample is 0.53 while the average adjusted correlation is 0.32. During the stability period, the average unadjusted correlation is 0.20 while the average adjusted correlation is 0.22. In many cases, the adjusted correlation coefficient is still greater during the turmoil period than the full period, but this increase is significantly diminished from that found in Table 2. For example, the unadjusted correlation between Hong Kong and the Netherlands jumps from 0.35 during the full period to 0.74 during the turmoil

[18] We continue to use the asymptotic distribution of this adjusted correlation coefficient.

Region	Country	Stability ρ	Stability σ	Turmoil ρ	Turmoil σ	Full Period ρ	Full Period σ	Test Stat.	Contag?
East Asia	Indonesia	0.413	0.042	0.399	0.244	0.428	0.037	-0.10	N
	Japan	0.252	0.045	0.255	0.290	0.263	0.042	-0.02	N
	Korea	0.098	0.046	0.380	0.257	0.173	0.044	0.69	N
	Malaysia	0.305	0.044	0.200	0.304	0.288	0.042	-0.26	N
	Philippines	0.315	0.044	0.388	0.253	0.323	0.041	0.22	N
	Singapore	0.348	0.043	0.343	0.288	0.348	0.040	-0.02	N
	Taiwan	0.010	0.046	0.058	0.331	0.028	0.046	0.08	N
	Thailand	0.051	0.046	0.171	0.312	0.082	0.045	0.25	N
Latin America	Argentina	0.033	0.046	-0.059	0.331	0.004	0.046	-0.17	N
	Brazil	0.113	0.046	-0.025	0.333	0.080	0.045	-0.28	N
	Chile	0.157	0.046	0.302	0.277	0.197	0.044	0.33	N
	Mexico	0.256	0.045	0.102	0.326	0.238	0.043	-0.37	N
OECD	Australia	0.385	0.042	0.561	0.191	0.431	0.037	0.57	N
	Belgium	0.153	0.046	0.371	0.254	0.178	0.044	0.65	N
	Canada	0.159	0.046	0.156	0.315	0.170	0.044	-0.04	N
	France	0.248	0.045	0.596	0.177	0.299	0.042	1.35	N
	Germany	0.412	0.042	0.642	0.162	0.450	0.036	0.97	N
	Italy	0.191	0.045	0.618	0.170	0.236	0.043	1.79	C
	Netherlands	0.346	0.043	0.397	0.246	0.347	0.040	0.18	N
	Spain	0.209	0.045	0.584	0.182	0.269	0.042	1.40	N
	Sweden	0.255	0.045	0.454	0.226	0.298	0.042	0.58	N
	Switzerland	0.200	0.045	0.519	0.205	0.232	0.043	1.16	N
	UK	0.278	0.044	0.292	0.279	0.280	0.042	0.04	N
	US	0.023	0.046	-0.169	0.313	-0.027	0.046	-0.40	N
Other Emerging Markets	India	0.101	0.046	0.009	0.333	0.089	0.045	-0.21	N
	Russia	0.285	0.044	0.569	0.188	0.365	0.040	0.89	N
	S. Africa	0.389	0.042	0.592	0.186	0.455	0.036	0.62	N

Table 3: 1997 East Asian Crises: Adjusted Correlation Coefficients

period, while the adjusted correlation only increases from 0.35 to 0.40. Moreover, when tests for contagion are performed on these adjusted correlations, only one coefficient (for Italy) increases significantly during the turmoil period. In other words, there is only evidence of contagion from the Hong Kong crash to one other country in the sample (versus fifteen cases of contagion when tests are based on the unadjusted coefficients.)

These results highlight exactly what we mean by contagion. Many stock markets are highly correlated with Hong Kong's market during this tumultuous period in October and November of 1997. For example, during this period the unconditional correlation between Hong Kong and Australia is 0.56 and that between Hong Kong and the Philippines is 0.39. These high cross-market correlations do not signify contagion, however, because these markets are also highly correlated during periods of relative stability. These stock markets are highly interdependent, both in periods of stability and turmoil, and are closely linked through trade and/or other real economic fundamentals. A continued high level of interdependence after a crisis does not constitute contagion.

4.1 Robustness Tests

Since this "no contagion, only interdependence" result is so controversial, and especially since the adjustment to the correlation coefficient has such a significant impact on our analysis, we perform an extensive array of robustness tests. In the following sections we test for the impact of: adjusting the frequency of returns and lag structure, modifying period definitions, altering the source of contagion, varying the interest rate controls, and estimating local currency returns. In each case (as well as others not reported below), the central result does not change. Tests based on the unadjusted correlation coefficients find some evidence of contagion, while tests based on the adjusted coefficients find virtually no evidence of contagion. Due to the repetition of these robustness tests, we only report summary results for each analysis.[19] We do, however, discuss any findings which are significantly different than those reported above.

4.1.1 Adjusting the Frequency of Returns and Lag Structure

As a first set of robustness tests, we adjust the frequency of returns and/or lag structure from that used above. In our base analysis, we focus on rolling-average, two-day returns in order to control

[19] Complete results are available from the authors.

for the fact that different stock markets are not open during the same hours. We also include five lags of the cross-market correlations (X_t) and the vector of interest rates (I_t) in order to control for any within-week variation in trading patterns. We repeat this analysis using daily returns and weekly returns. We also combine each of these return calculations with zero, one, or five lags (as possible) of X_t and I_t. Note that in each case, estimates are only consistent if there are at least as many lags (minus one) as the number of days averaged to calculate the returns.[20] Results are reported in Table 4.

Return Frequency and Lag Structure	**Cases of Contagion**	
	Unadjusted ρ	**Adjusted ρ**
daily + 0 lags	17	0
daily + 1 lag	17	0
daily + 5 lags	17	1
2 day + 1 lag	15	0
2 day + 5 lags	**15**	**1**
weekly + 5 lags	13	2

Table 4: 1997 East Asian Crises: Robustness to Adjusting the Frequency of Returns and/or Lag Structure

This table shows that adjusting the frequency of returns and/or lag structure does not significantly change our central results. When cross-market correlations are estimated based on the unadjusted correlation coefficient, there is evidence of contagion from Hong Kong to about half the sample. When cross-market correlations are based on the adjusted correlations, there is almost no evidence of contagion. No matter which frequency of returns and number of lags are included in the estimation of equation 7, there are at most two cases where cross-market correlations increase significantly after the October crash of the Hong Kong market.

[20] Lags are required because we utilize a moving average to measure returns. Therefore, by construction, observations at time t are correlated with those at $t-1$, $t-2$, etc. There are two methods of solving this problem. First, include lags in the regression (as we do). Second, change the frequency of the data and reduce the number of observations. If there are no holidays, or the holidays are the same across countries then both procedures should be identical. If the missing observations differ across countries (as they do in our sample), it is easier to control for this problem using the first technique.

Also note that we do not use more than five lags due to the short length of the turmoil period.

4.1.2 Modifying Period Definitions

For a second set of robustness tests, we modify definitions for the periods of turmoil and relative stability. In our base estimation, we define the period of turmoil as starting on October 17, 1997 (the start of the publicized Hong Kong crash) and lasting one month. We repeat this analysis, extending this turmoil period to either: start on June 1, 1997 (when the Thai market first crashed); start on August 7,1997 (when the Indonesian and Thai markets began their simultaneous, dramatic one-month plunge); or end on March 1, 1998 (the end of the sample). Also, in the original estimation, we define the period of relative stability as lasting from January 1, 1996 through October 16, 1997. We extend this period by three years and one year. Summary results based on these different period definitions are reported in Table 5.

Turmoil Period	Stability Period	Cases of Contagion	
		Unadjusted ρ	Adjusted ρ
10/17/97 - 11/16/97	**01/01/96 - 10/16/97**	**15**	**1**
06/01/97 - 11/16/97	01/01/96 - 05/31/97	2	0
08/07/97 - 11/16/97	01/01/96 - 08/06/97	7	0
10/17/97 - 03/01/98	01/01/96 - 10/16/97	16	0
10/17/97 - 11/16/97	01/01/93 - 10/16/97	17	0
10/17/97 - 11/16/97	01/01/95 - 10/16/97	16	1

Table 5: 1997 East Asian Crises: Robustness to Modifying Period Definitions

Modifying the definitions of the turmoil or stability periods does not change the central result; there is virtually no evidence of contagion when tests are based on the adjusted correlation coefficients. Moreover, it is interesting to note that when the turmoil period is extended to before the dramatic Hong Kong crash, tests based on the unadjusted correlation coefficients indicate much less contagion. When the turmoil period is extended after the Hong Kong crash, however, tests based on the unadjusted correlation coefficients do indicate contagion. This is not surprising, given that market volatility increased significantly after the Hong Kong crash (and it is this volatility that generates a bias in the unadjusted correlation coefficient.) This also supports our hypothesis that the Hong Kong crash is the most likely catalyst driving any contagion.

4.1.3 Altering the Source of Contagion

As a third sensitivity test, we examine how altering the defined source of contagion can impact our results. As discussed above, one difficulty in testing for contagion during the East Asian crisis is that there is no single event acting as a clear catalyst driving this turmoil. For example, during June the Thai market plummeted, during August the Indonesian market cratered, and in October the Hong Kong market crashed. We focus on the Hong Kong crash as the impetus behind any contagion due to the sudden change in global sentiment after this event. It was not until the Hong Kong crash that concerns about Asia became headline news, and the discussion began on the East Asian "crisis" and the possibility of "contagion" to the rest of the world. In this section, we test if events in other countries, or even groups of countries, would be a more accurate catalyst driving contagion during the later half of 1997.

We begin by testing for contagion from single East Asian markets after a significant downturn in those markets. For example, we test for contagion from Thailand after its June crash, from Thailand or Indonesia after their August crashes, or from Korea after its two-month crash starting in late October. (In each case, we end the stability period directly before the crash.)

Next, since contagion may occur from the combined impact of movements in several East Asian markets, instead of movement in any one market, we construct several indices of East Asian markets. For each index, we weight each country by total market capitalization at the end of 1996, as reported in Table 1. We test for contagion: from Thailand and Indonesia after the August crashes in both of these markets; from Hong Kong and Korea during several tumultuous periods in these markets; and from Hong Kong, Indonesia, Korea, Malaysia, and Thailand (a five-country index) during several different periods. Summary results for all of these tests are reported in Table 6.

This table shows that altering the source of contagion during the East Asian crisis does not significantly change our central results.[21] Tests for contagion based on single East Asian markets

[21] Also note that for each of these alternative sources of contagion, we have performed the same senstivity tests as reported for the Hong Kong base case (i.e. adjusting the frequency of returns and lag structure, modifying period definitions, changing the controls for aggregate shocks, and estimating local currency returns.)

Contagion Source	Turmoil Period	Full Period	Cases of Contagion	
			Unadjusted ρ	Adjusted ρ
Hong Kong	**10/17/97 - 11/16/97**	**01/01/96 - 11/16/97**	**15**	**1**
Thailand	06/01/97 - 06/30/97	01/01/96 - 06/30/97	0	0
Thailand	08/07/97 - 09/06/97	01/01/96 - 09/06/97	2	0
Indonesia	08/07/97 - 09/06/97	01/01/96 - 09/06/97	5	0
Korea	10/23/97-12/22/97	01/01/96 - 12/22/97	0	0
Indon., Thail.	08/07/97 - 09/06/97	01/01/96 - 09/06/97	7	0
H.K., Korea	10/17/97 - 11/16/97	10/17/97 - 11/16/97	16	2
H.K., Korea	10/17/97 - 12/23/97	01/01/96 - 12/23/97	12	0
H.K., Korea	10/17/97 - 03/01/97	01/01/96 - 03/01/98	0	0
5-country index	10/17/97 - 12/23/97	01/01/96 - 12/23/97	6	0
5-country index	08/07/97 - 12/23/97	01/01/96 - 12/23/97	2	0
5-country index	08/07/97 - 03/01/98	01/01/96 - 03/01/98	7	0

Table 6: 1997 East Asian Crises: Robustness to Altering the Source of Contagion

or indices combining these markets all indicate that there was virtually no contagion from these sources to markets around the world.

4.1.4 Varying the Interest Rate Controls

For a fourth robustness test, we vary the interest rate controls. As discussed in Section 2, we utilize interest rates to control for any aggregate shocks and/or monetary policy coordination which could simultaneously affect different stock markets. Specifically, in the formulation of equation 7 we control for interest rates in Hong Kong, the US and country j. We repeat this analysis using no controls for interest rates, just controlling for the US interest rate (as a measure of aggregate shocks) and just controlling for interest rates in Hong Kong and country j (to control for monetary policy coordination.) Table 7 summarizes these results.

This table clearly shows that our results are highly robust to changing the interest rates controls, or even eliminating them completely.

4.1.5 Utilizing Local Currency Returns

As a final sensitivity test, we repeat the previous tests utilizing returns based on local currency instead of US dollars. Test results based on local currency returns, with a number of different lag

Interest Rates Included	Cases of Contagion	
	Unadjusted ρ	Adjusted ρ
$i_t^{HK}, i_t^{US}, i_t^{j}$	**15**	**1**
None	15	0
i_t^{US}	15	0
i_t^{HK}, i_t^{j}	15	0

Table 7: 1997 East Asian Crises: Robustness to Varying the Interest Rate Controls

and return structures, are reported in Table 8.

Return Frequency and Lag Structure	Cases of Contagion	
	Unadjusted ρ	Adjusted ρ
daily + 0 lags	14	0
daily + 1 lag	14	0
daily + 5 lags	16	1
2 day + 1 lag	16	1
2 day + 5 lags	**14**	**2**
weekly + 5 lags	12	4

Table 8: 1997 East Asian Crises: Robustness Tests Based on Local Currency Returns

Measuring returns based on local currencies instead of US dollars clearly has minimal impact on our central results.

4.1.6 Summary: Robustness Tests

In our base test for contagion during the 1997 East Asian crisis, we find evidence of contagion between Hong Kong and 15 countries when tests are based on the unadjusted correlation coefficients. When the same tests are based on the adjusted correlation coefficients, there is only one case of contagion. We perform an extensive array of tests to see if these results are robust. We adjust the frequency of returns and/or lag structure, modify period definitions, alter the source of contagion, vary the interest rate controls, and estimate local currency returns. In each case, the central result does not change. When tests are based on the unadjusted correlation coefficients, there is evidence of contagion in about half the sample (with the number of cases highly dependent on the specification estimated), but when tests are based on the adjusted coefficients, there is virtually no evidence of contagion.

Therefore, these results suggest far less contagion from the East Asian crisis than previously believed. Unconditional, cross-market correlations between Hong Kong and each of the countries in our sample (with the possible exception of Italy) did not increase significantly after the Hong Kong crash in October of 1997. High correlations between Hong Kong and any other markets during this period did not result from a significant shift in cross-market linkages. Instead, any high cross-market correlations during this tumultuous period reflect continued interdependence, not contagion, across countries.

5 Contagion During the 1994 Mexican Peso Crisis

As our second set of analyses of how the bias in the correlation coefficient affects tests for contagion, we compare cross-market correlations before and after the Mexican peso crisis of 1994. In December of 1994, the Mexican government suffered a balance of payments crisis, leading to a collapse of the peso and a crash in the Mexican stock market. This crisis generated fears that contagion could quickly lead to crises in other emerging markets and especially in the rest of Latin America. This analysis is more straightforward than that during the East Asian crisis due to the existence of one clear catalyst (the collapse of the peso) driving any contagion.

For our base test, we define the period of turmoil in the Mexican market as lasting from 12/19/94 (the day the exchange rate regime was abandoned) through 12/31/94. We define the period of relative stability as 1/1/93 through 12/31/95 (excluding the period of turmoil). Next, we estimate the same system of equations as above (equation 7), but replace returns and interest rates for Hong Kong with those of Mexico. We continue to calculate returns as rolling, two-day averages and to utilize five lags for $\phi(L)$ and $\Phi(L)$. Then we repeat the standard test for stock market contagion: test for a significant increase in cross-market correlations during the period of turmoil in the Mexican market. Estimates of the unadjusted correlation coefficients and test results are shown in Table 9.

These unadjusted correlation coefficients show many patterns similar to the East Asian case. First, during the relatively stable period, the Mexican market tends to be more highly correlated with markets in the same region (such as other Latin American countries and the US). Second, cross-market correlations between Mexico and most countries in the sample increase during the

Region	Country	Stability		Turmoil		Full Period		Test	
		ρ	σ	ρ	σ	ρ	σ	Stat.	Contag?
East Asia	Hong Kong	0.055	0.037	0.467	0.391	0.070	0.036	0.93	N
	Indonesia	0.042	0.037	0.194	0.481	0.049	0.036	0.28	N
	Japan	0.028	0.037	0.426	0.409	0.036	0.036	0.87	N
	Korea	0.035	0.037	0.721	0.240	0.058	0.036	2.40	C
	Malaysia	0.048	0.037	-0.064	0.498	0.042	0.036	-0.20	N
	Philippines	0.066	0.037	-0.067	0.498	0.061	0.036	-0.24	N
	Singapore	0.068	0.037	0.194	0.481	0.070	0.036	0.24	N
	Taiwan	0.092	0.036	0.526	0.362	0.097	0.036	1.08	N
	Thailand	0.047	0.037	0.101	0.495	0.045	0.036	0.10	N
Latin America	Argentina	0.382	0.031	0.859	0.131	0.401	0.031	2.84	C
	Brazil	0.384	0.031	0.791	0.187	0.402	0.031	1.79	C
	Chile	0.309	0.033	0.426	0.409	0.298	0.033	0.29	N
OECD	Australia	0.078	0.036	0.565	0.340	0.092	0.036	1.26	N
	Belgium	0.039	0.037	0.636	0.298	0.052	0.036	1.75	C
	Canada	0.136	0.036	0.333	0.444	0.135	0.036	0.41	N
	France	0.097	0.036	0.139	0.490	0.093	0.036	0.09	N
	Germany	0.001	0.037	0.332	0.444	0.011	0.036	0.67	N
	Italy	-0.002	0.037	-0.504	0.373	-0.016	0.036	-1.19	N
	Netherlands	0.044	0.037	0.652	0.288	0.054	0.036	1.84	C
	Spain	0.139	0.036	0.120	0.492	0.134	0.036	-0.03	N
	Sweden	0.105	0.036	-0.213	0.477	0.095	0.036	-0.60	N
	Switzerland	0.005	0.037	0.182	0.483	0.010	0.036	0.33	N
	UK	0.097	0.036	0.284	0.460	0.096	0.036	0.38	N
	US	0.207	0.035	0.118	0.493	0.196	0.035	-0.15	N
Other Emerging Markets	India	0.013	0.037	-0.017	0.500	0.012	0.036	-0.05	N
	Russia	-0.009	0.037	0.077	0.497	-0.008	0.036	0.16	N
	S. Africa	0.062	0.037	0.710	0.248	0.073	0.036	2.24	C

Table 9: 1994 Mexican Peso Crisis: Unadjusted Correlations in Stock Market Returns

period of turmoil. This is a prerequisite for contagion to occur. Many developed countries which are not highly correlated with Mexico during the period of stability become highly correlated during the period of turmoil. Third, the t-tests indicate that there is a significant increase (at the 5% level) in the correlation coefficient during the turmoil period for six countries. According to the interpretation used in previous empirical work, this indicates that contagion occurred from the crash of the Mexican stock market in 1994 to Argentina, Belgium, Brazil, Korea the Netherlands, and South Africa. As discovered above, however, these increases in the correlation coefficient might not actually constitute contagion. Instead, they may result from the bias due to increased market volatility during this tumultuous period. Therefore, we repeat the above tests, using equation 6 to correct for this bias. Estimated correlation coefficients and test results are shown in Table 10.

		Stability		Turmoil		Full Period		Test	
Region	**Country**	ρ	σ	ρ	σ	ρ	σ	**Stat.**	**Contag?**
East Asia	Hong Kong	0.058	0.037	0.172	0.460	0.070	0.036	0.21	N
	Indonesia	0.044	0.037	0.065	0.493	0.049	0.036	0.03	N
	Japan	0.029	0.037	0.154	0.467	0.036	0.036	0.24	N
	Korea	0.037	0.037	0.339	0.387	0.058	0.036	0.66	N
	Malaysia	0.051	0.037	-0.021	0.499	0.042	0.036	-0.12	N
	Philippines	0.070	0.037	-0.022	0.499	0.061	0.036	-0.15	N
	Singapore	0.072	0.037	0.067	0.493	0.070	0.036	-0.01	N
	Taiwan	0.097	0.037	0.200	0.448	0.097	0.036	0.21	N
	Thailand	0.049	0.037	0.034	0.498	0.045	0.036	-0.02	N
Latin America	Argentina	0.398	0.033	0.500	0.307	0.401	0.031	0.29	N
	Brazil	0.403	0.033	0.390	0.358	0.402	0.031	-0.03	N
	Chile	0.325	0.034	0.151	0.467	0.298	0.033	-0.29	N
OECD	Australia	0.082	0.037	0.223	0.438	0.092	0.036	0.28	N
	Belgium	0.041	0.037	0.260	0.420	0.052	0.036	0.46	N
	Canada	0.143	0.036	0.116	0.480	0.134	0.036	-0.04	N
	France	0.103	0.036	0.046	0.497	0.093	0.036	-0.09	N
	Germany	0.001	0.037	0.113	0.481	0.011	0.036	0.20	N
	Italy	-0.002	0.037	-0.189	0.453	-0.016	0.036	-0.35	N
	Netherlands	0.046	0.037	0.273	0.414	0.054	0.036	0.49	N
	Spain	0.146	0.036	0.040	0.498	0.134	0.036	-0.17	N
	Sweden	0.111	0.036	-0.071	0.492	0.095	0.036	-0.31	N
	Switzerland	0.005	0.037	0.061	0.494	0.010	0.036	0.09	N
	UK	0.102	0.036	0.097	0.486	0.096	0.036	0.00	N
	US	0.218	0.036	0.039	0.498	0.196	0.035	-0.29	N
Other Emerging Markets	India	0.015	0.037	-0.006	0.500	0.012	0.036	-0.03	N
	Russia	-0.010	0.037	0.026	0.499	-0.008	0.036	0.06	N
	S. Africa	0.065	0.037	0.314	0.394	0.073	0.036	0.56	N

Table 10: 1994 Mexican Peso Crisis: Adjusted Correlations in Stock Market Returns

Once again, adjusting for the bias from changing market volatility has a significant impact on estimated cross-market correlations and the resulting tests for contagion. In each country, the adjusted correlation is substantially smaller (in absolute value) than the unadjusted correlation during the turmoil period and is slightly greater in the stability period. In many cases, the adjusted correlation coefficient is still greater during the turmoil period than during the stability period, but this increase is significantly diminished from that found in Table 9. For example, for the full period, the cross-market correlation between Mexico and Argentina is 0.40. In the period of turmoil, the unadjusted correlation jumps to 0.86, while the adjusted correlation jumps to only 0.50. When tests for contagion are performed on these adjusted correlations, there is not one case in which the correlation coefficient increases significantly during the turmoil period. In other words, there is no longer evidence of contagion from Mexico in 1994 to any other country in the sample. Even Argentina and Brazil, which were frequently cited as examples of contagion after the Mexican peso crisis, are not subject to contagion (as defined in this paper).

An extensive set of robustness tests supports these central results. We adjust the frequency of returns and lag structure, modify period definitions, vary the interest rate controls, and/or estimate local currency returns. While the evidence of contagion based on the unadjusted coefficient does vary (from 0 to 7) based on the specification estimated, whenever the coefficient is adjusted to remove any bias from heteroscedasticity, there is virtually no evidence of contagion.[22]

Therefore, these results suggest that there was minimal (if any) contagion from the Mexican peso crisis. Cross-market correlations between Mexico and each of the countries in our sample never increase significantly after the collapse of the peso (when returns are measured in US dollars). Any markets which are highly correlated with Mexico during this period of turmoil are also highly correlated during periods of relative stability. For example, the Mexican and Argentinian markets are highly correlated after the Mexican peso collapse–with an unconditional correlation coefficient of 0.50. This is not contagion, however, because these two markets are traditionally highly correlated–with an unconditional correlation coefficient during the entire period of 0.40. Cross-market correlations are therefore not significantly different during the peso crisis. These two stock markets are highly interdependent, both in periods of stability and turmoil. They are closely linked through trade and other real economic fundamentals.

[22] In all of these tests based on the adjusted coefficients, there are never more than two cases of contagion. These cases only occur when returns are measured in local currency, and often occur in unexpected countries, such as India and South Africa.

6 Contagion During the 1987 US Stock Market Crash

Before the East Asian crisis and Mexican peso collapse, another period of stock market turmoil when investors feared contagion was after the US stock market crash in October of 1987. As discussed in the literature review of Section 2, this period is the focus of most empirical work on stock market contagion. To test for contagion during this period, we repeat the test procedure described above. We define the period of turmoil as October 17, 1987 (the date of the original crash) through December 4, 1987 (the nadir of the US market) and define the period of relative stability as January 1, 1986 through the October crash. Since many of the smaller stock markets in our sample of 28 countries were not in existence or were highly regulated at this time, we focus only on the ten largest stock markets (including the US). Once again, we focus on two-day, rolling-average, US dollar returns and control for five lags of returns and interest rates. Results based on the unadjusted and adjusted correlation coefficients are reported in Tables 11 and 12.

	Stability		**Turmoil**		**Full Period**		**Test**	
Country	ρ	σ	ρ	σ	ρ	σ	**Stat.**	**Contag?**
Australia	-0.199	0.045	-0.106	0.202	-0.180	0.044	0.30	N
Canada	0.515	0.034	0.635	0.122	0.531	0.032	0.68	N
France	0.169	0.045	0.610	0.128	0.256	0.042	2.08	C
Germany	0.105	0.046	0.492	0.155	0.172	0.044	1.61	N
Hong Kong	0.154	0.045	0.091	0.202	0.139	0.044	-0.20	N
Japan	-0.015	0.046	0.167	0.198	0.005	0.044	0.67	N
Netherlands	0.246	0.044	0.662	0.115	0.325	0.040	2.18	C
Switzerland	0.160	0.045	0.552	0.142	0.221	0.043	1.79	C
UK	0.145	0.045	0.645	0.119	0.212	0.043	2.67	C

Table 11: 1987 U.S. Stock Market Crash: Unadjusted Correlation Coefficients

	Stability		**Turmoil**		**Full Period**		**Test**	
Country	ρ	σ	ρ	σ	ρ	σ	**Stat.**	**Contag?**
Australia	-0.209	0.045	-0.007	0.203	-0.180	0.044	0.46	N
Canada	0.528	0.038	0.497	0.152	0.531	0.032	-0.18	N
France	0.176	0.046	0.441	0.159	0.256	0.042	0.92	N
Germany	0.110	0.046	0.352	0.176	0.172	0.044	0.82	N
Hong Kong	0.162	0.046	0.057	0.203	0.139	0.044	-0.33	N
Japan	-0.015	0.046	0.107	0.201	0.005	0.044	0.42	N
Netherlands	0.256	0.045	0.500	0.149	0.325	0.040	0.93	N
Switzerland	0.165	0.046	0.431	0.165	0.221	0.043	1.01	N
UK	0.150	0.046	0.502	0.150	0.212	0.043	1.50	N

Table 12: 1987 U.S. Stock Market Crash: Adjusted Correlation Coefficients

Most patterns are similar to those found after the 1997 East Asian crisis and 1994 Mexican peso collapse. First, tests for a significant increase in cross-market correlations based on the unadjusted correlation coefficients show a substantial amount of contagion–in almost one-half of the sample.

Second, when the correlation coefficients are adjusted to correct for changing market volatility, these tests find no evidence of contagion. Third, many of the adjusted cross-market correlations are relatively large during the period of turmoil, but since there is no significant change in cross-market linkages, these large correlations indicate a high level of interdependence, and not contagion, across countries.

Finally, as discussed in Section 4, these results may not be robust to: adjusting the frequency of returns and lag structure; modifying period definitions; varying the interest rate controls; and estimating local currency returns. We repeat each of these sensitivity tests and find that results are extremely robust. When tests are based on the unadjusted correlation coefficient, there is always contagion from the US to several markets after the October crash. When tests are based on the adjusted correlation coefficients, there is never more than one case of contagion (and usually zero cases). This is in sharp contrast to the papers discussed in Section 2. Each of these earlier papers which tested for contagion after the 1987 US stock market crash found evidence of a significant increase in cross-market linkages during this period. None of these papers, however, adjusted the correlation coefficient to correct for heteroscedasticity. The extensive robustness tests performed for this paper show that after adjusting the correlation coefficient to remove this bias, there is virtually no evidence of contagion from the US to other major stock markets after the 1987 crash.

7 Conclusion and a New Puzzle

The first three sections of this paper discuss techniques for examining market co-movements and testing for contagion. Contagion is narrowly defined as a significant increase in cross-market linkages after a shock to one country (or group of countries). Section 3 shows that the correlation coefficient underlying conventional tests for contagion is biased. This correlation coefficient is actually conditional on market volatility over the time period under consideration, so that during a period of turmoil when stock market volatility increases, unadjusted estimates of cross-market correlations will be biased upward. This can erroneously lead us to accept that contagion occurred. We show a simple method of adjusting the correlation coefficient to correct for this bias. This adjusted correlation coefficient, while clearly an improvement over that used in past work measuring stock market co-movements, can still be biased in the presence of endogeneity or unobservable aggregate shocks.

The final three sections of the paper apply these concepts to test for contagion during three periods of market turmoil: the 1997 East Asian crisis, the 1994 Mexican peso collapse, and the 1987 US stock market crash. Each section performs a number of tests evaluating if average cross-market correlations increase significantly during the relevant period of turmoil. In each of these periods, tests based on the unadjusted correlation coefficients suggest that there was contagion in several markets. When the same tests are based on the adjusted correlation coefficients, however, the incidence of contagion falls dramatically–to zero in most cases. Three key results continually emerge from this battery of tests. First, when testing for contagion across stock markets, it is critically important to measure market co-movements accurately. Adjusting the correlation coefficient to correct for heteroscedasticity will not only affect estimates of cross-market correlations, but can significantly reduce estimates of stock market contagion. Second, when these adjusted correlation coefficients are applied to the standard tests for contagion, we find significantly less evidence of contagion during the East Asian crisis, the Mexican peso collapse, and the US stock market crash, than previously believed. In fact, in most of these tests, there is not a single case of contagion. Third, when these results are combined with the observed high level of market co-movement during these periods of market turmoil, it highlights exactly what we mean by contagion in this paper. Contagion is not simply a high cross-market correlation after a shock. It is a significant increase in this correlation after the shock. The high levels of co-movement across many stock markets during these three tumultuous periods reflects a continuation of strong cross-market linkages, and not a significant shift in these linkages. In other words, during the recent Asian crisis, the Mexican peso collapse, and the 1987 US market crash, continued strong cross-market linkages suggest interdependence instead of contagion.

These results are highly robust to: adjusting the frequency of returns and/or lag structure; modifying period definitions; altering the source of contagion; varying the interest rate controls; and estimating local currency returns. These results, however, should be interpreted cautiously because the adjustment for heteroscedasticity may change in the presence of endogeneity and/or aggregate shocks. The critical point of this paper and its extensive series of tests is that inferences based on the unadjusted correlation coefficient can be extremely misleading. Simple adjustments can reverse what appear to be straightforward conclusions. This paper presents a technique for adjusting for one problem with the cross-market correlation coefficient: heteroscedasticity. Future work needs to examine how endogeneity and aggregate shocks can affect this adjustment, as well as designing new techniques to simultaneously correct for these three econometric problems.

Taken as a whole, these results suggest a new direction for research on stock market co-movements. Stock markets in many countries are highly integrated, and this high level of co-movement is fairly constant in all states of the world. There does not appear to be a significant change in how markets are linked during crisis periods. This paper suggests that future research does not need to focus on how international propagation mechanisms change after a shock. Instead, research should focus on why markets are so highly integrated during periods of relative stability (as well as periods of crisis). Crisis periods could be used as windows to help identify these transmission mechanisms, instead of interpreted as periods which generate new types of transmission mechanisms. In other words, we should focus not on why some countries are so vulnerable during periods of crisis, but why countries are always so vulnerable to movements in other countries. Why do so many markets of such different sizes, structures, and geographic locations generally show such a high degree of co-movement? Are these diverse markets linked by trade and other economic fundamentals? Or is there an "excess interdependence" across stock markets in all states of the world?

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A Proof of the Bias in the Unadjusted Correlation Coefficient

Assume x and y are two stochastic variables that have the following relationship,

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

where $E[\varepsilon_t] = 0$, $E\left[\varepsilon_t^2\right] < \infty$, and $E[x_t \varepsilon_t] = 0$. Note that it is not necessary to make any further assumptions about the distribution of the residuals. Divide the sample into two sets so that the variance of x_t is lower in the first group (l) and higher in the second group (h) .Since $E[x_t \varepsilon_t] = 0$ by assumption, OLS estimates of the above equation are consistent and efficient for both groups, so that $\beta^h = \beta^l$.

Next, define:

$$1 + \delta \equiv \frac{\sigma_{xx}^h}{\sigma_{xx}^l}$$

then,

$$\begin{aligned} \sigma_{yy}^h &= \beta^2 \sigma_{xx}^h + \sigma_{ee} \\ &= \beta^2 (1+\delta) \sigma_{xx}^l + \sigma_{ee} \\ &= \left(\beta^2 \sigma_{xx}^l + \sigma_{ee}\right) + \delta \beta^2 \sigma_{xx}^l \\ &= \sigma_{yy}^l + \delta \beta^2 \sigma_{xx}^l \\ &= \sigma_{yy}^l \left(1 + \delta \beta^2 \frac{\sigma_{xx}^l}{\sigma_{yy}^l}\right) \end{aligned}$$

and when this is combined with:

$$\rho = \frac{\sigma_{xy}}{\sigma_x \sigma_y} = \beta \frac{\sigma_x}{\sigma_y}$$

then:

$$\sigma_{yy}^h = \sigma_{yy}^l \left(1 + \delta \left[\rho^l\right]^2\right)$$

Therefore,

$$
\begin{aligned}
\rho^{h} &= \frac{\sigma^{h}_{xy}}{\sigma^{h}_{x}\sigma^{h}_{y}} \\
&= \frac{(1+\delta)\,\sigma^{l}_{xy}}{(1+\delta)^{1/2}\,\sigma^{l}_{x}\left(1+\delta\,[\rho^{l}]^{2}\right)^{1/2}\sigma^{l}_{y}} \\
&= \rho^{l}\cdot\sqrt{\frac{1+\delta}{1+\delta\,[\rho^{l}]^{2}}} \qquad (9)
\end{aligned}
$$

The correlation coefficient is clearly an increasing function of δ. Moreover, equation 9 shows the adjustment that must be made to the conditional correlation in order to estimate the unconditional moment.