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NO CONTAGION, ONLY INTERDEPENDENCE: MEASURING STOCK MARKET CO-MOVEMENTS

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ABSTRACT

This paper examines stock market co-movements. It begins with a discussion of several conceptual issues involved in measuring these movements and how to test for contagion. Standard tests examine if cross-market correlation in stock market returns increase during a period of crisis. The measure of cross-market correlations central to this standard analysis, however, is biased. The unadjusted correlation coefficient is conditional on market movements over the time period under consideration, so that during a period of turmoil when stock market volatility increases, standard estimates of cross-market correlations will be biased upward. It is straightforward to adjust the correlation coefficient to correct for this bias.

The remainder of the paper applies these concepts to test for stock market contagion during the 1997 East Asian crises, the 1994 Mexican peso collapse, and the 1987 U.S. stock market crash. In each of these cases, tests based on the unadjusted correlation coefficients find evidence of contagion in several countries, while tests based on the adjusted coefficients find virtually no contagion. This suggests that high market co-movements during these periods were a continuation of strong cross-market linkages. In other words, during these three crises there was no contagion, only interdependence.

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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 states of market turmoil constitute contagion? Or are global markets so interdependent that they have similar high rates of co-movement in all states of the world?

Economists have developed a straightforward approach to measuring contagion across stock markets. They compare the correlation (or covariance) between two stock markets during a relatively stable period (generally measured as a historic average) to that during a period of turmoil (directly after a shock occurs). Contagion is defined as a significant increase in the cross-market correlation during the period of turmoil. According to this approach, if two markets are moderately correlated during periods of stability, such as Germany and Italy, and then a shock to one market has ripple effects and leads to a significant increase in market co-movement, this would constitute contagion. On the other hand, if two markets, are traditionally highly correlated, such as the U.S. and Canada, even if they continue to be highly correlated after a shock to one market, this may not necessarily constitute contagion. It is only contagion if the cross-market correlation increases significantly. If the correlation does not increase significantly, then any continued high level of market co-movement suggests strong real linkages between the two economies–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.

Evaluating if contagion occurs is important for several reasons. First, a critical tenet of investment strategy is that most economic disturbances are country specific, so stock markets in different countries should display relatively low correlations. International diversification would therefore substantially reduce portfolio risk and increase expected returns. If contagion occurs after a negative shock, however, then market correlations would increase in bad states, which would undermine much of the rational for international diversification. Second, many models of investor behavior (which will be discussed below) are based on the assumption that investors react differently after a large negative shock. Understanding how individual behavior changes in good and bad states is key to understanding how shocks are transmitted across markets. Third, many international institutions and policy makers worry that a negative shock to one country can have a negative impact on financial flows to another country–even if the fundamentals of the second economy are strong and there is little real connection between the two countries. Even if this effect is temporary, it could lead to a financial crisis in the second country–a crisis completely unwarranted by the country's fundamentals and policies. If this sort of contagion exists, it could justify I.M.F. intervention and the dedication of massive amounts of money to stabilization funds. For all of these reasons, it is important to evaluate if, and under what circumstances, contagion occurs.

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 develops a simple framework through which to interpret the propagation mechanisms of international shocks. It briefly reviews the relevant theoretical and empirical literature and places it in the context of this framework. 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 movements 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.

Sections 4 through 6 apply these concepts to test for contagion during three periods of market turmoil: the 1997 East Asian crises, the 1994 Mexican peso collapse, and the 1987 U.S. stock market crash. Each section tests 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 crises, the Mexican peso collapse, and the 1987 U.S. market crash, were a continuation of strong cross-market interdependence instead of contagion. The final section of the paper summarizes these findings and mentions 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 measuring 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

Theoretical work on the international propagation of shocks can be broadly categorized as focusing on three different mechanisms: aggregate shocks which affect the economic fundamentals of more than one country, country-specific shocks which affect the economic fundamentals of other countries, and shocks which are not explained by fundamentals and are categorized as pure contagion.[1]

The first mechanism focuses on aggregate or global shocks which simultaneously affect the fundamentals of several economies. For example, a rise in the international interest rate, a contraction of the international supply of capital, or a decline in international demand could simultaneous slow growth in a number of countries. The stock markets 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 any affected countries could increase.

The second mechanism explains how a shock to one country (or group of countries) could affect fundamentals in other countries.[2] This mechanism could work through a number of real linkages,

[1] See Masson [1997] for further discussion on these three propagation mechanisms.

[2] See Eichengreen, Rose and Wypolsz [1996] for a discussion of these mechanisms. See Gerlach and Smets [1995] for further information on the trade channel.

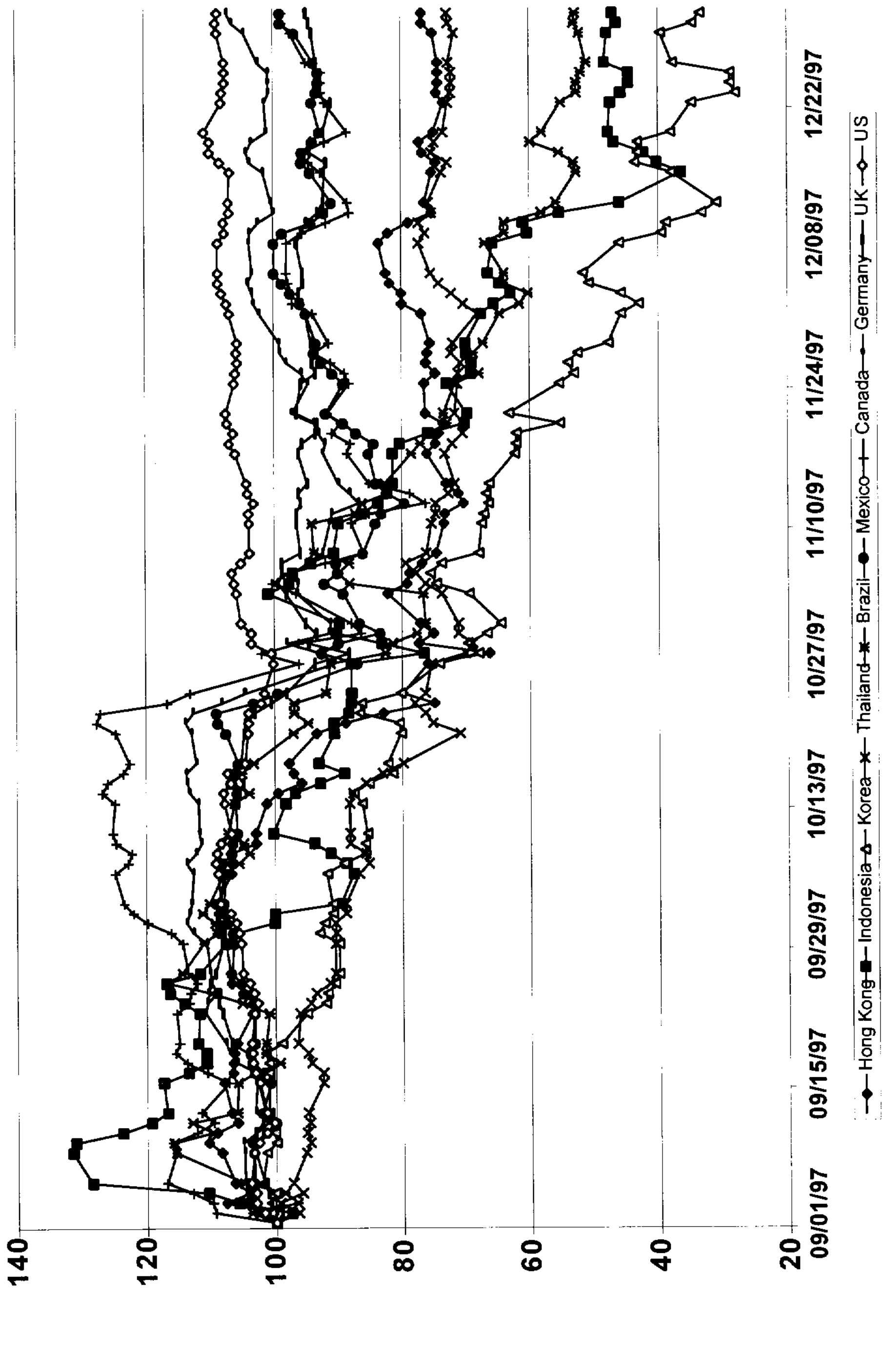

Figure 1: 1997 East Asian Crises. Stock Market Indices in US$.

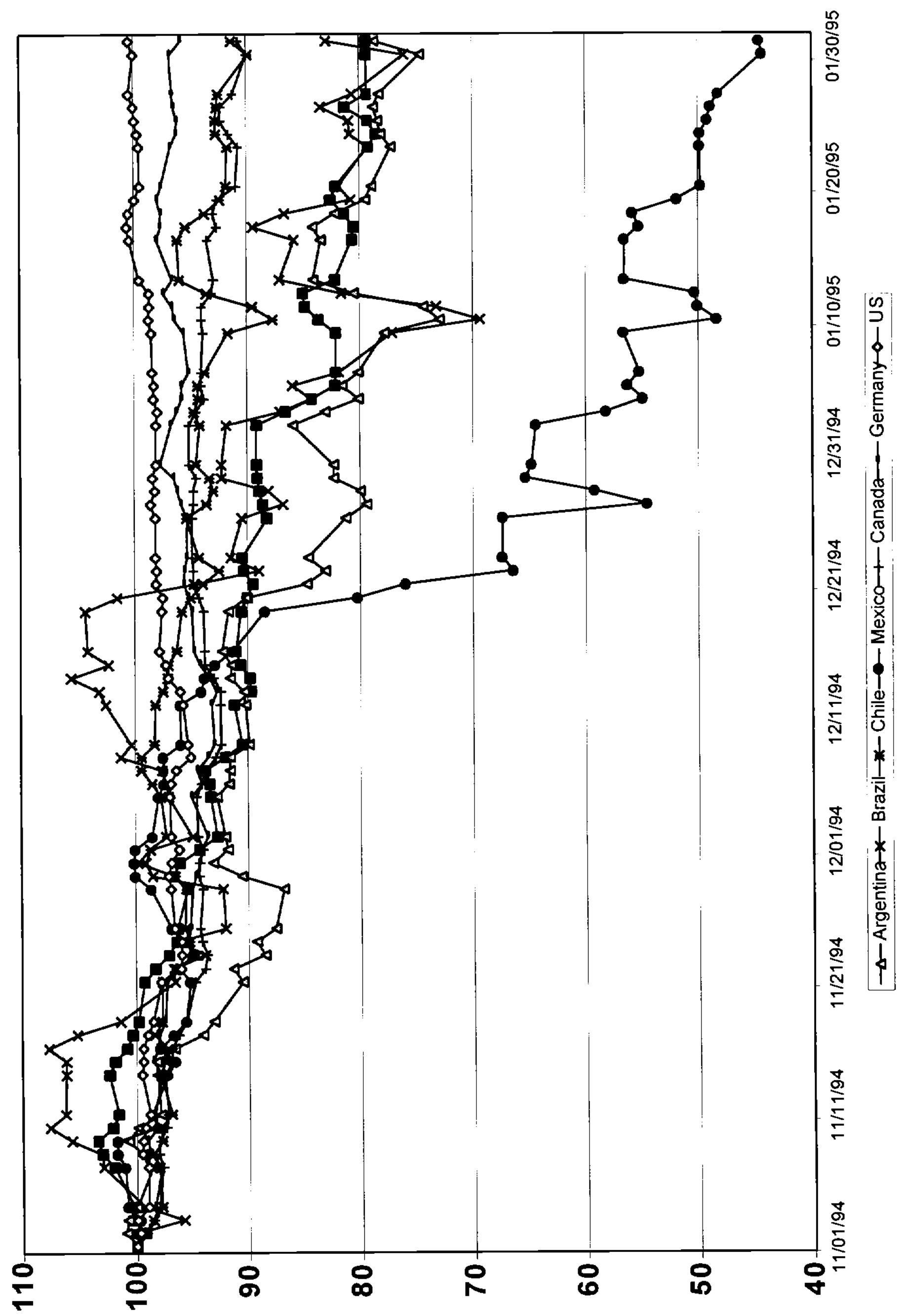

Figure 2: 1994 Mexican Peso Collapse. Stock Market Indices in US$.

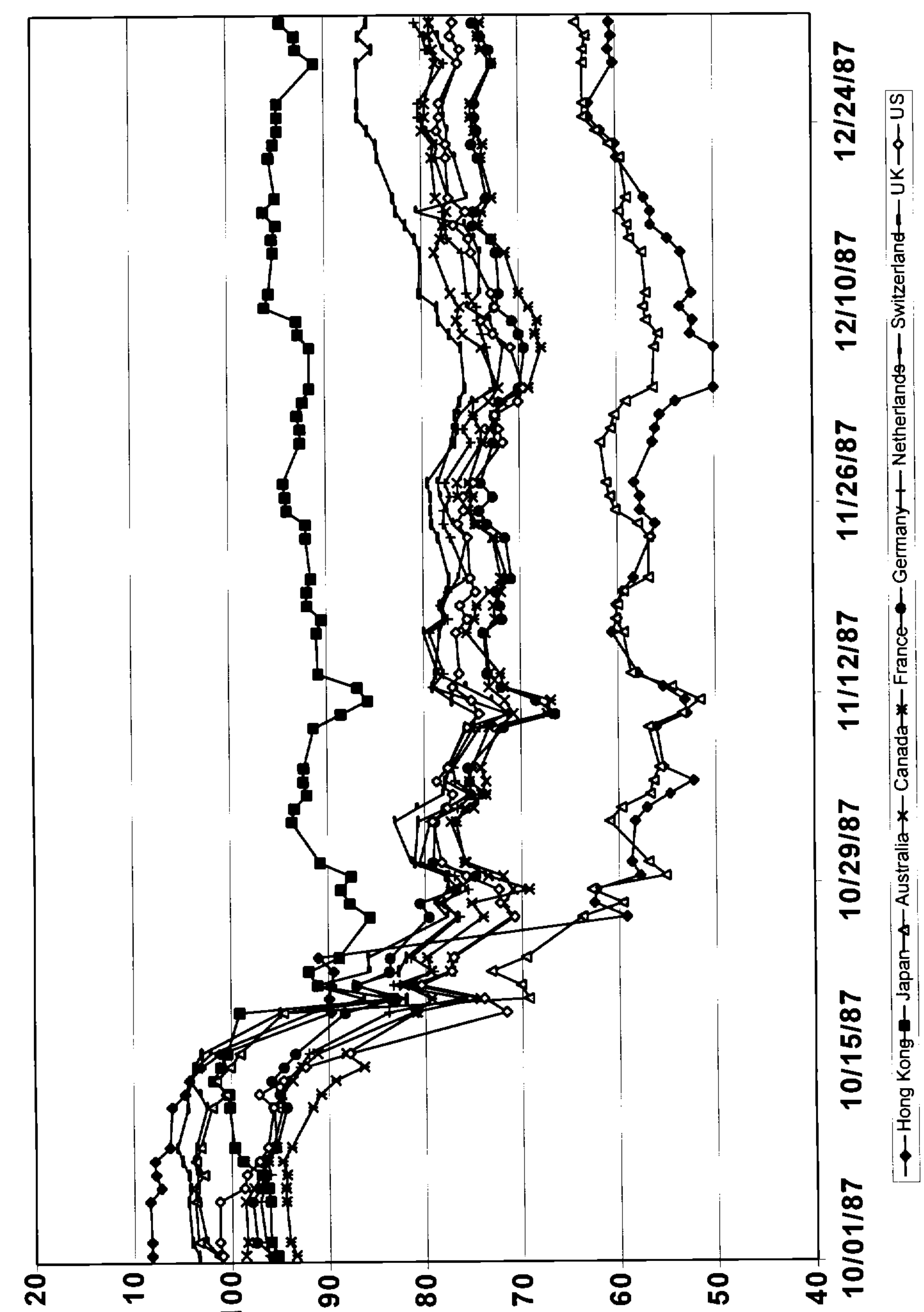

Figure 3: 1987 U.S. Stock Market Crash. Stock Market Indices in US$.

such as trade or policy coordination. Trade could link economies because a devaluation in one country would increase the competitiveness of that country's goods, potentially decreasing the competitiveness of other countries. This could not only have a direct affect 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 the country's currency. Policy coordination could link 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 would force other member countries to raise trade barriers.

The final international propagation mechanism, contagion, is defined as any increased market co-movement which can not be explained by the previous two channels.[3] Theories explaining contagion are based on multiple equilibria, capital market liquidity, investor psychology, and/or political economy. Masson [1997] presents a theory of multiple equilibria which shows that a crisis in one country can be used as a sun-spot for another. The shift from a good to a bad equilibrium is driven by a change in investor expectations (and not by any real linkages.) Valdés [1996] develops a model based on capital market liquidity and argues that a crisis in one country can cause a liquidity shock to market participants. This could force a portfolio recomposition and drive a sell-off of certain asset classes, which would lower asset prices in countries not affected by the initial crisis. Mullainathan [1998] focuses on investor psychology and 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. Finally, Drazen [1998] proposes that political economy can drive price co-movements, such as during the European devaluations of 1993. For example, if political pressure drives central bank presidents to maintain an existing exchange rate regime, then when one country abandons its regime, this would reduce the political costs of other countries changing their regimes. This effect could generate bunching in the timing of economic policy shifts.

Although these theories of contagion are based on very different mechanisms, they all generate

[3] The obvious problem with this definition is that contagion is treated as the residual. As a result, we might erroneously accept the existence of contagion because we do not understand or capture the real spillovers between economies.

the same critical conclusion: that cross-market linkages during a crisis are different than during relatively stable periods. For example, in the multiple equilibria, investor psychology, or political economy cases, a change in cross-market correlations is driven by a change in the expectations or beliefs of investors (or policy makers). In the capital market example, a change in cross-market correlations is driven by investor liquidity constraints. In each case, international propagation mechanisms are strengthened during a crisis and this shift is not driven by real economic linkages.

2.2 Propagation Mechanisms: A Framework

The last section outlined three broad propagation mechanisms: aggregate shocks which affect the economic fundamentals of more than one country, country-specific shocks which affect the economic fundamentals of other countries, and shocks which are not explained by fundamentals and are categorized as pure contagion. These three 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 the first propagation mechanism, aggregate shocks, is measured by the variable a_t, and the direct effect of these shocks on each country i is captured by the vector γ_i. The second mechanism, the 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. Since each form of contagion, the third propagation mechanism, involves a change in cross-market linkages, contagion is captured by a change in either β_i or γ_i.

One problem with the direct estimation of equation 1 is endogeneity. For example, not only would economic fundamentals and stock prices in country i affect those in country j, but fundamentals and prices in country j could affect those in country i. This is immediately apparent in the two country case. Assume that the stock prices in the two countries are x_t and y_t then the structural form determining these prices can be written as:

$$x_t = \alpha_x + \beta_x y_t + \gamma_x a_t + \varepsilon_x \quad (2)$$

$$y_t = \alpha_y + \beta_y x_t + \gamma_y a_t + \varepsilon_y \quad (3)$$

where a_t is the same aggregate shock as defined above and ε_x and ε_y are idiosyncratic and independent country-specific shocks. In order to estimate this structural form in equations 2 and 3, it is necessary to find exogenous events (such as high frequency news) to identify the parameters. In most cases, however, this procedure is not feasible, since it depends on finding events which affect only one equation. In other words, in order to identify β_x it is necessary to find events such that $\varepsilon_y = 0$ and $\varepsilon_x \neq 0$.

There is, however, an alternative procedure to test for contagion. This procedure focuses on the reduced form (a variant of equation 1 which will be discussed below) and tests for significant changes in parameter estimates across periods. More specifically, if real cross-country linkages do not change across time, then the coefficients of equation 1 should remain constant across periods. If we force the coefficients to be equal across time and estimate equation 1 for the full period under consideration and for a shorter period of market turmoil, then any changes in actual coefficient values during the period of market turmoil will be reflected as changes in the variance-covariance matrix. A significant change in the variance-covariance matrix during this turmoil period would therefore indicate a shift in cross-market linkages–i.e. contagion. The disadvantage of this test is that since the actual parameters of equation 1 can not be accurately computed, it is impossible to estimate the strength of the various real propagation mechanisms. The advantage of this procedure, however, is that it tests for contagion but does not require us to make any difficult (or impossible) identification assumptions.

2.3 Propagation Mechanisms: Previous Empirical Work

While empirical papers testing for contagion have utilized both of the procedures outlined above, the majority have focused on some variant of the second procedure due to the difficulty in finding exogenous events to identify equations 2 and 3.[4] Only two papers have attempted to use news as the identifying condition for the first procedure. Eichengreen, Rose & Wyplosz [1996] utilize the collapse of fixed exchange rates in the ERM at the end of 1993 (with one country's collapse taken as the exogenous event) to compute the probability that one country's crisis affects the probability of other countries facing a crisis. They find that the probability of a country suffering a speculative attack increases when another country in the ERM is under attack, and that the initial shock is propagated primarily through trade. Baig & Goldfajn [1998] study the impact of daily news in one country's stock market (the exogenous event) on other countries markets during the recent East Asian crises. They find that a substantial proportion of a country's news impacts neighboring economies.

Most of the other papers attempting to measure stock market contagion focus on the second approach: testing for changes in the variance-covariance matrix during periods of market turmoil. The majority of these papers test for contagion directly after the U.S. stock market crash of 1987. In one of the first such papers, King & Wadhwani [1990] test for an increase in cross-market correlations between the U.S., U.K. and Japan. They find that correlations increase significantly after the U.S. stock market crash. Lee & 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. Bertero & Mayer [1990] focus on how the shock of the U.S. crash was propagated across markets. They show that the impact differed by country and that market vulnerability was not significantly related to market size nor average volume. They do find, however, that the impact was larger in markets with circuit breakers and/or capital controls. Chuo [1994] and Hamao [1990] further extend these tests by using an auto-regressive conditional heteroscedasticity (ARCH) framework to estimate the variance-covariance matrices. They find that there is evidence of significant spill-overs across markets and that this international transmission of volatility does not occur evenly across countries.

Finally, several papers take a different approach and focus on the long-run relationship between markets instead of any short-run changes after a shock. These papers use the same basic procedures as above, except test for changes in the co-integrating relationship between stock markets instead

[4]This literature is quite extensive, so the following section will only highlight work closely related to this paper's analysis.

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 U.S. and other countries have risen by about 0.36 over this period.[5] This approach is a very weak test for contagion, however, since it assumes that real linkages between markets (such as trade flows or monetary coordination) remain constant. If tests show that the co-integrating relationship has increased over time, this suggests either contagion or an increase in real cross-market linkages (which is likely given the long time periods under consideration.)

3 Measuring Contagion

3.1 Bias in the Correlation Coefficient

While these empirical tests for stock market contagion have utilized a number of different methodologies and procedures, the analytic tool underlying this work is the unadjusted correlation coefficient. This section shows that this unadjusted correlation coefficient is biased, and this bias is especially large during the periods of market turmoil that are the focus of these tests. This discussion builds on Ronn [1998], which addresses this bias in the estimation of intra-market correlations in stocks and bonds.[6] 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. 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:

$$y_t = \alpha + \beta x_t + \varepsilon_t \tag{4}$$

where $E[\varepsilon_t] = 0,\ E[\varepsilon_t^2] < \infty$, and $E[x_t \varepsilon_t] = 0$.[7] Note that it is not necessary to make any further

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

[6] 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.

[7] These assumptions are critical to obtain the results reported in this paper. If endogeneity or aggregate unobservable shocks exist, then the Gauss-Markov assumptions are not satisfied and the adjustment to the correlation

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 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 4 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:

$$\beta^h = \frac{\sigma_{xy}^h}{\sigma_{xx}^h} = \frac{\sigma_{xy}^l}{\sigma_{xx}^l} = \beta^l \tag{5}$$

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 4, 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,

$$\left(\frac{\sigma_{xx}}{\sigma_{yy}}\right)^h > \left(\frac{\sigma_{xx}}{\sigma_{yy}}\right)^l \tag{6}$$

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coefficient is slightly different than that presented here. We do not use this alternative adjustment in this paper, however, since it is extremely difficult (and impossible in many cases) to estimate for stock markets. Rigobon [1998] discusses these issues in more depth. Preliminary results from Rigobon [1998] suggest that any endogeneity and/or unobservable aggregate shocks have little impact on the results reported in this paper. Alternative test procedures which address these problems reinforce the results reported below.

Finally, substitute 5 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 6, 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 actual correlation between x and y does not change. In other words, this standard, 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. Specifically:

$$\rho_t^u = \rho_t \sqrt{\frac{1 + \delta_t}{1 + \delta_t \rho_t^2}} \tag{7}$$

where ρ_t^u is the unadjusted (or conditional) correlation coefficient, ρ_t is the actual (or unconditional) correlation coefficient, and δ_t is the relative increase in the variance of x_t:

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

Equation 7 clearly shows that the estimated correlation coefficient increases in δ. Therefore, during periods of increased 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 7 to solve for the unconditional correlation yields:

$$\rho_t = \frac{\rho_t^u}{\sqrt{1 + \delta_t \left[1 - (\rho_t^u)^2\right]}} \tag{8}$$

To clarify the intuition and relevance of this adjustment, Figure 4 graphs the correlation in stock market returns between Hong Kong and the Philippines during 1997.[8] 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 changes in market volatility 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 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 exists. The remainder of this paper examines if this bias in the correlation coefficient has a significant impact on estimates of cross-market correlations and tests for contagion during the 1997 East Asian crises, the 1994 Mexican peso collapse, and the 1987 U.S. 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 U.S. dollars and in local currency, and in most cases, the currency unit does not affect our central findings. Since U.S. 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 U.S. dollars in the discussion below. (We continue to report estimates based on local returns if results are significantly different.) Moreover, U.S. dollar returns have the additional advantage of controlling for inflation (under non-fixed exchange rate regimes).

[8] 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.

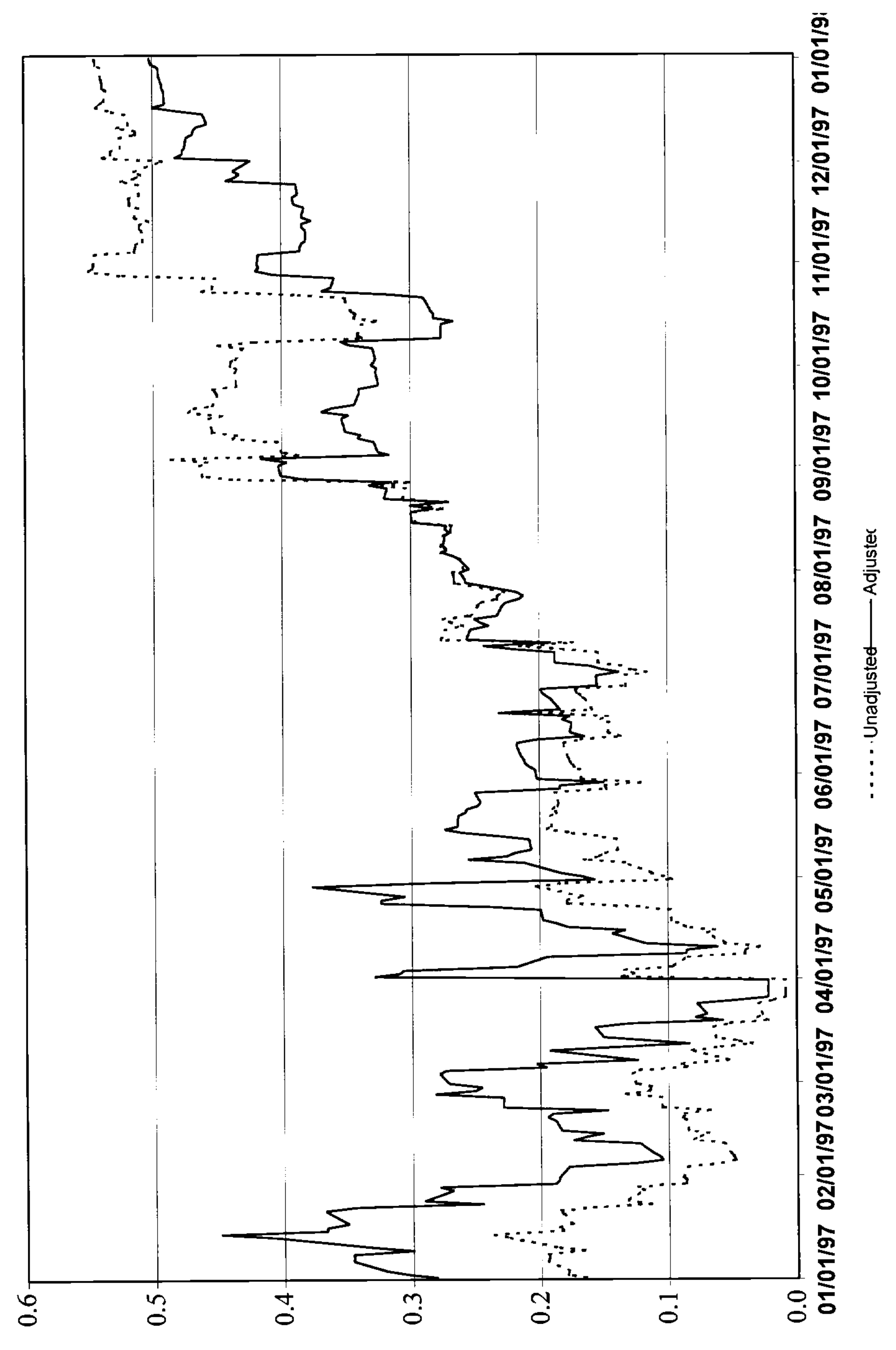

Figure 4: Cross-Market Correlations: Hong Kong and the Philippines.

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 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.[9] It also defines the regions utilized throughout this paper.

4 Contagion During the 1997 East Asian Crises

As our first analysis of the impact of bias in the correlation coefficient, we test for contagion during the East Asian crises 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 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

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

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
	U.K.	1740.3	578.5
	U.S.	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

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, however, 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.[10] 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:

$$\begin{aligned} X_t &= \phi(L)X_t + \Phi(L)I_t + \eta_t & (9) \\ X_t &\equiv \left\{x_t^{HK}, x_t^j\right\}' & \\ I_t &\equiv \left\{i_t^{HK}, i_t^{US}, i_t^j\right\}' & (10) \end{aligned}$$

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 U.S. and country j, respectively, and η_t is a vector of reduced-form disturbances. We utilize average two-day returns 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

[10] 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.

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 changing market volatility. Finally, we use a t-test to evaluate if there is a significant increase in these correlation coefficients during the period of turmoil.[11] If ρ is the correlation during the full period and ρ_t^h is the correlation during the turmoil period, the test hypotheses are:

$$H_0 \;:\; \rho \geq \rho_t^h$$
$$H_1 \;:\; \rho < \rho_t^h$$

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.

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

[11] 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
	U.K.	0.255	0.043	0.615	0.201	0.280	0.042	1.34	N
	U.S.	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

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 increased market volatility 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 8 to adjust for this bias. In other words, we repeat the above analysis using the unconditional instead of the conditional correlation coefficients.[12] Estimated, adjusted correlation coefficients and test results are shown in Table 3.

It is immediately apparent that 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. 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 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 cor-

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

Region	Country	Stability		Turmoil		Full Period		Test	
		ρ	σ	ρ	σ	ρ	σ	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
	U.K.	0.278	0.044	0.292	0.279	0.280	0.042	0.04	N
	U.S.	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

related 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.[13] 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 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

[13]Complete results are available from the authors.

as many lags (minus one) as the number of days averaged to calculate the returns.[14] 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 correlation, there is almost no evidence of contagion. No matter which frequency of returns and number of lags are included in the estimation of equation 9, there are at most two cases where cross-market correlations increase significantly after the October crash of the Hong Kong market.

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

[14]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.

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 crises 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.

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

This table shows that altering the source of contagion during the East Asian crises does not significantly change our central results.[15] Tests for contagion based on single East Asian markets 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 9 we control for interest rates in Hong Kong, the U.S. and country j. We repeat this analysis using no controls for interest rates, just controlling for the U.S. 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.

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

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 U.S. dollars. Test results based on local currency returns, with a number of different lag

[15] 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.)

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 U.S. 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 crises, we find evidence of contagion between Hong Kong and 15 countries when tests are based on the unadjusted correlation coefficients, but only one case of contagion when tests are based on the adjusted correlation coefficients. 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 crises 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 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 crises 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 9), 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 U.S.) Second, cross-market correlations between Mexico and most countries in the sample increase during the 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 be 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 8 to correct

Region	Country	Stability		Turmoil		Full Period		Test	
		ρ	σ	ρ	σ	ρ	σ	Stat.	Contag?
East	Hong Kong	0.055	0.037	0.467	0.391	0.070	0.036	0.93	N
Asia	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	Argentina	0.382	0.031	0.859	0.131	0.401	0.031	2.84	C
America	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
	U.K.	0.097	0.036	0.284	0.460	0.096	0.036	0.38	N
	U.S.	0.207	0.035	0.118	0.493	0.196	0.035	-0.15	N
Other	India	0.013	0.037	-0.017	0.500	0.012	0.036	-0.05	N
Emerging	Russia	-0.009	0.037	0.077	0.497	-0.008	0.036	0.16	N
Markets	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

for this bias. Estimated correlation coefficients and test results are shown in Table 10.

Region	Country	Stability		Turmoil		Full Period		Test	
		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
	U.K.	0.102	0.036	0.097	0.486	0.096	0.036	0.00	N
	U.S.	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 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.

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 changing market volatility, there is virtually no evidence of contagion.[16]

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 U.S. 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.

6 Contagion During the 1987 U.S. Stock Market Crash

Before the East Asian crises and Mexican peso collapse, another period of stock market turmoil when investors feared contagion was after the U.S. 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 U.S. market) and define the period of relative

[16] 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.

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 U.S.). Once again, we focus on two-day, rolling-average, U.S. 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 crises 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 U.S. 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 U.S. 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 changing market volatility. 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 U.S. to other major stock markets after the 1987 crash.

7 Conclusions and a New Puzzle

The first three sections of this paper discuss concepts underlying the measurement of stock market co-movements and the conventional techniques of testing for contagion across these markets. Section 2 develops a simple framework through which to interpret international propagation mechanisms and explains how contagion is defined as a significant shift in these mechanisms during periods of crisis. Section 3 shows that the correlation coefficient underlying these 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 by 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 crises, the 1994 Mexican peso collapse, and the 1987 U.S. 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. 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.

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 changing market volatility 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 crises, the Mexican peso collapse, and the U.S. 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. 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 U.S. market crash, continued strong cross-market linkages suggest interdependence instead of contagion.

These key results suggest a new direction for research on stock market co-movements. Focusing on how shocks are transmitted during periods of crisis, or how international propagation mechanisms change after a shock, may not be the most productive approach. Instead, this paper suggests that we should focus on why markets are so highly integrated during periods of relative stability (as well as periods of crisis). 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?

References

Baig, T. and Goldfajn, I. (1998). Financial markets contagion in the asian crises. *IMF Mimeo.*

Bertero, E. and Mayer, C. (1990). Structure and performance: Global interdependence of stock markets around the crash of october 1987. *European Economic Review*, 34:1155–1180.

Cashin, P., Kumar, M., and McDermott, C. J. (1995). International integration of equity markets and contagion effects. *IMF Working Paper WP/95/110.*

Chou, R., Ng, V., and Pi, L. (1994). Cointegration of international stock market indices. *IMF Working Paper WP/94/94.*

Drazen, A. (1998). Political contagion in currency crisis. *University of Maryland Mimeo.*

Eichengreen, B., Rose, A., and Wyplosz, C. (1996). Contagious currency crises. *NBER Working Paper 5681.*

Gerlach, S. and Smets, F. (1995). Contagious speculative attacks. *European Journal of Political Economy*, 11:45–63.

Hamao, Y., Masulis, R., and Ng, V. (1990). Correlations in price changes and volatility across international stock markets. *The Review of Financial Studies*, 3(2):281–307.

King, M. and Wadhwani, S. (1990). Transmission of volatility between stock markets. *Review of Financial Studies*, 3(1):5–33.

Lee, S. B. and Kim., K. J. (1993). Does the october 1987 crash strengthen the co-movements among national stock markets? *Review of Financial Economics*, 3(1):89–102.

Longuin, F. and Slonik, B. (1995). Is the correlation in international equity returns constant: 1960-1990. *Journal of International Money and Finance*, 14(1):3–26.

Masson, P. (1997). Monsoonal effects, spillovers, and contagion. *IMF Mimeo.*

Mullainathan, S. (1998). A memory based model of bounded rationality. *MIT Mimeo.*

Ronn, E. (1998). The impact of large changes in asset prices on intra-market correlations in the stock and bond markets. *Mimeo.*

Valdés, R. (1996). Emerging market contagion: Evidence and theory. *MIT Mimeo.*

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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 $E[\varepsilon_t] = 0$, $E[\varepsilon_t^2] < \infty$, 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,

$$\rho^h = \frac{\sigma^h_{xy}}{\sigma^h_x \sigma^h_y}$$
$$= \frac{(1+\delta)\,\sigma^l_{xy}}{(1+\delta)^{1/2}\,\sigma^l_x \left(1+\delta\,[\rho^l]^2\right)^{1/2} \sigma^l_y}$$
$$= \rho^l \cdot \sqrt{\frac{1+\delta}{1+\delta\,[\rho^l]^2}} \tag{11}$$

The correlation coefficient is clearly an increasing function of δ. Moreover, equation 11 shows the adjustment that must be made to the conditional correlation in order to estimate the unconditional moment.