Measuring financial contagion: Detecting changes in cross-market linkages with structural break tests

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Abstract

Traditionally, tests for financial contagion have been performed under the assumption that periods of higher correlation between a pair of countries coincide identically with a crisis. This paper contributes to the literature by using the Bai and Perron (2003a) structural break test to relax this assumption, determining both the start and end dates of contagious episodes. In particular, I apply this framework to a modified version of the newly proposed Morales and Andreosso-O'Callaghan (2014) test, showing that without these modifications the test consistently overestimates the presence of contagion. The results indicate that contagion processes are widely varied in terms of of both timing and length. Furthermore, I find many significant negative coefficients, generally clustered around the run-up to a crisis, suggesting that markets often become less correlated just before a crisis. I also allows pre- and post-crisis interdependence structures to vary, finding that, in most cases, market correlations increase again in the post-crisis period.

Contents

1 Introduction

The 2007 global financial crisis resulted in the sudden and simultaneous collapse of financial markets around the world, leaving in its wake the question of how crises can spread between so many seemingly healthy economies within such a short period of time. In fact, the rapid spread of financial turmoil among countries is not a characteristic unique to the recent financial crisis. The East Asian financial crisis spread quickly throughout the region after the Hong Kong stock market crashed in October 1997, the Mexican Peso crisis in 1994 is thought to have contaminated markets in South America, and the U.S. market crash of 1987 sparked turmoil in the United Kingdom and Japan. This characteristic of crises to spread from one country to another, mirroring the properties of a medical virus, is known as financial contagion and refers to the transmission of financial shocks beyond what should be expected through normal economic linkages. However, there is little consensus in the literature as to whether contagion is truly present during financial crises. Traditional measurement techniques have been shown to suffer from endogeneity, heteroskedasticity, omitted variable bias, and sensitivity to the selection of the crisis dates. This research will build on the recent literature addressing these issues by integrating the structural break test of Bai and Perron (2003a) with a modified version of the new methodology proposed by Morales and Andreosso-O'Callaghan (2014). In doing so I show not only the bias of the Morales and Andreosso-O'Callaghan (2014) test, which fails to account for normal market interaction, but the invalidity of the assumption that crises and contagion occur at the same time, implicit in most contagion studies.

Figure 1 shows stock indices for the United States, the United Kingdom, Japan, France, Germany, and Canada, six of the largest developed economies. The United States, the United Kingdom, and Japan were the subjects of early contagion studies focussing on the market crash of 1987. While this episode provided the early inspiration behind financial contagion, the literature quickly moved on to more sub-

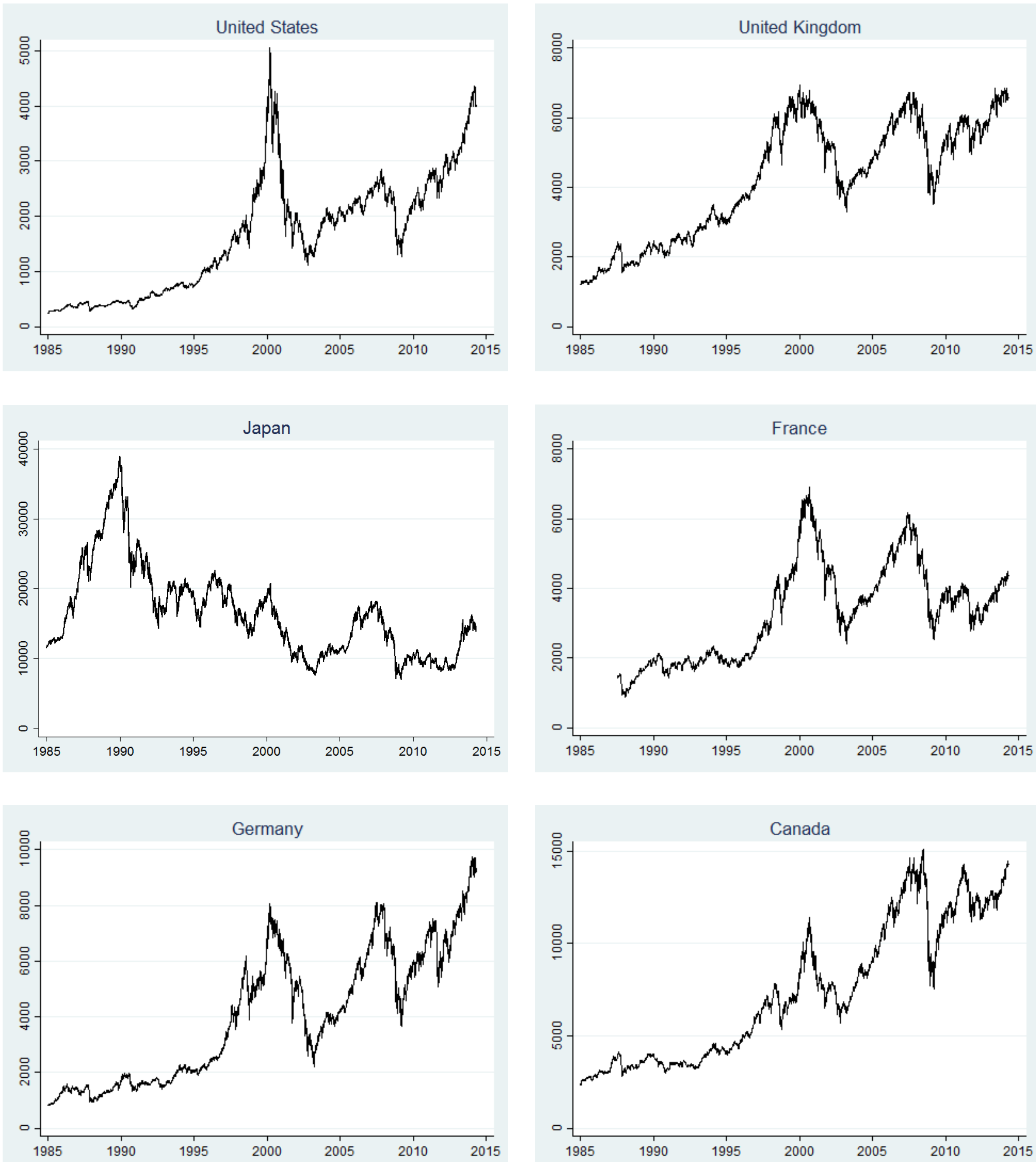


Figure 1: Stock market indices of The United States, The United Kingdom, Canada, France, Germany and The Netherlands

stantial financial crises, lasting many months or more rather than a few days or weeks. France and Germany represent the two largest economies in Europe, share a common currency, and are highly integrated through real economic linkages during tranquil periods. Canada is a major trading partner with the United States and is heavily affected by the economic fluctuations of its southern neighbour.

The figure emphasizes three stock market crashes: the Asian financial crisis in the late 1990s, the market crash in 2000 as a result of the bursting of the dot-com bubble, and the financial crisis of 2007. Notice that, while the series may display a moderate degree of correlation during normal times, in periods of crisis they seem to collapse uniformly, implying that stock markets become more correlated during crisis episodes. This structural change is the idea behind financial contagion: that crises are able to spread quickly between countries because markets become more integrated during periods of turmoil.

Contagion is most commonly defined as "[...] a significant increase in cross-market linkages after a shock to an individual country (or group of countries), as measured by the degree to which asset prices or financial flows move together across markets relative to this comovement in tranquil times" (Claessens et al., 2000, p.178). Two details implicit in this definition are worth emphasizing. First, an increase in cross-market linkages implies a break in the normal interdependence structure between two or more countries. Specifically, if contagion is present, markets should appear to be more correlated during a crisis compared to tranquil times. Hence, early methods of testing for contagion focussed on measuring for differences in stock market correlations before and after a crisis. Second, the distinction between tranquil and turmoil periods requires a well defined "shock" to separate these times. While traditionally crises have been dated *ad hoc* by researchers to match historical events, more recent work incorporates endogenous break tests to determine the crisis periods objectively from the data. This is especially important for events such as the Asian financial crisis which lack a clear starting point. This method has also been used to detect and date breaks in the interdependence structure between two countries, rather than the crisis itself. In this context break tests are absolutely essential because changes in the interdependence structure are not observed, unlike crises themselves which can be often seen in the data.

An often overlooked but important issue is the dating of the *end* of the crisis, and hence the determination of the entire crisis period. Somewhat surprisingly, while the issue of crisis dating has garnered much attention in recent studies, even these often ignore the issue of estimating the entire crisis period rather than simply the start date. This is an important factor in contagion measurement and can matter both from an economic and methodological perspective. Indeed, the results of Forbes and Rigobon (2002) which offer the strongest evidence against financial contagion have been shown to actually support the contagion hypothesis when the crisis period is extended. To avoid this issue I utilize the Bai and Perron (2003a) structural break test, which is capable of detecting multiple breaks, and hence estimates the entire contagious period.

The speed with which the 2007 crisis devastated financial markets around the world has shown the need for more research into the mechanisms by which crises spread. Billio and Pelizzon (2003) motivate the importance of contagion research by noting that if contagion is present during financial crises then portfolio diversification may not be a sufficient means to ensure against risk. As the authors state, "Indeed, a critical assumption of investment strategies is that most economic disturbances are country-specific. As a consequence, stock in different countries should be less correlated. However, if market correlation increases after a bad shock, this would undermine much of the rationale for international diversification" (Billio and Pelizzon, 2003, p.409). Hence, from a financial stability perspective the question of whether or not markets become more correlated during crises is an important one. By relaxing the assumption that contagion occurs coincident with a crisis episode, this paper contributes to our understanding of financial markets by observing that, while many countries show evidence of contagion effects, the break in the interdependence structure rarely coincides with the crisis dates. Furthermore, many countries actually show a significant decrease in correlation before a crisis, a fact that may cause biased estimates and misleading results in other contagion studies.

Contagion research is also frequently used to clarify the role that international financial institutions should play in managing crises. Contagion implies that otherwise healthy economies are at risk of becoming infected with the financial turmoil of other markets. Thus, there is some grounds for organizations such as the International Monetary Fund to provide assistance to infected countries as a means of containing the crisis. If, on the other hand, contagion is not observed, then crises could be viewed as a result of weak economic fundamentals. In this case policy makers would do better to take steps to improve these fundamentals. While the evidence put forth in this paper suggests that many studies overestimate the presence of contagion, I still find many significant episodes of contagion. This might suggest that the likelihood of a country falling victim to a contagious spell is largely beyond its control, and international intervention is an appropriate measure to stop the spread of crises. The remainder of this paper proceeds as follows: Section 2 overviews the recent literature, Section 3 describes the data and methodology, Section 4 presents the empirical results, Section 5 discusses the major findings, and Section 6 concludes.

2 Literature Review

The literature on financial contagion begins with the work of King and Wadhwani (1990), who model the increase in stock market correlations through a partial information model. The authors begin with the stock market crash of October 1987, observing that world stock markets collapsed concurrently and with remarkable similarity, "[...] despite important differences in economic prospects, market mechanisms, and their prior 'degree of overvaluation' " (King and Wadhwani, 1990, p.30). Tables 1 and 2 offer some anecdotal evidence of contagion, reporting summary statistics for the stock returns of select East Asian countries in the pre-crisis and crisis periods.[1] Of particular interest are the correlation matrices in each period. In nearly every case the correlation coefficient between a given pair of countries is higher in the crisis period. This observation motivated the work of King and Wadhwani (1990) and lead to the popularity of tests based on changes in correlation coefficients.

Table 1: Pre-crisis descriptive statistics (January 1, 1995 - June 19, 1997)

	Hong Kong	Korea	Indonesia	Malaysia	Thailand	Philippines
Descriptive Statistics						
Mean	0.001	0.000	0.000	0.000	-0.002	0.000
Standard Deviation	0.008	0.009	0.006	0.007	0.010	0.008
Minimum	-0.037	-0.034	-0.033	-0.029	-0.042	-0.035
Maximum	0.034	0.031	0.027	0.026	0.035	0.032
Correlation Matrix						
Hong Kong	1.000					
Korea	0.078	1.000				
Indonesia	0.357	-0.002	1.000			
Malaysia	0.464	0.018	0.392	1.000		
Thailand	0.321	-0.018	0.327	0.339	1.000	
Philippines	0.313	0.054	0.448	0.371	0.303	1.000

To test for contagion, King and Wadhwani (1990) analyze stock market correlation coefficients between pairs of countries before and after the U.S. market crash of October 1987. A statistically significant increase in the correlation coefficient would imply that contagion is present. Using this approach they find an increase in the correlation coefficients between the U.S. and both the U.K. and Japan, suggesting that contagion was present at this time. In a similar study, Baig and Goldfajn (1999) find evidence of contagion in the exchange rates, stock markets, and interest rates of Korea, Malaysia, the Philippines, and Thailand during the 1997 East Asian crisis.

[1] The crisis dates are determined using the Bai and Perron (2003a) test over the sample period January 1, 1995 to December 31, 1999. This exercise is carried out in Section 4.2 but we use the same dates here for consistency. These are the dates according with the crisis in Thailand, which is found to have started earlier and lasted longer than the corresponding crisis in Hong Kong. I show the data for these countries because of the Asian financial crisis is by far the most popular in contagion work.

Table 2: Crisis period descriptive statistics (June 20, 1995 - March 12, 1999)

	Hong Kong	Korea	Indonesia	Malaysia	Thailand	Philippines
Descriptive Statistics						
Mean	-0.001	-0.001	-0.002	-0.002	-0.001	-0.001
Standard Deviation	0.019	0.022	0.021	0.022	0.020	0.018
Minimum	-0.104	-0.071	-0.079	-0.074	-0.056	-0.070
Maximum	0.067	0.075	0.074	0.176	0.108	0.089
Correlation matrix						
Hong Kong	1.000					
Korea	0.317	1.000				
Indonesia	0.445	0.273	1.000			
Malaysia	0.422	0.306	0.402	1.000		
Thailand	0.382	0.353	0.430	0.357	1.000	
Philippines	0.517	0.255	0.452	0.347	0.487	1.000

However, as Forbes and Rigobon (2002) show, tests based on correlation coefficients are biased in the presence of heteroskedasticity, which is almost certainly present in the data. Returning to Tables 1 and 2, not only are the correlation coefficients higher in the crisis period but also the standard deviation of asset returns. As a result, changes in the correlation coefficients could simply be because of a change in the volatility and not an indication that contagion is actually present. To account for this, Forbes and Rigobon (2002) propose a modified correlation coefficient that corrects for heteroskedasticity. Using this corrected correlation coefficient they find only one case of contagion during the Asian financial crisis. Comparatively, the unadjusted correlation coefficient finds contagion in more than half of the cases.

Dungey et al. (2005) show that the Forbes and Rigobon (2002) methodology can also be implemented in a regression framework by scaling the stock returns of each market by their respective standard deviations in the tranquil period. Consider the following:

$$\left(\frac{y_t}{\sigma_{y_1}}\right) = \gamma_0 + \gamma_1 d_t + \gamma_2 \left(\frac{x_t}{\sigma_{x_1}}\right) + \gamma_3 \left(\frac{x_t}{\sigma_{x_1}}\right) d_t + \eta_t \tag{1}$$

where d_t is a dummy variable equal to one during the crisis period and zero otherwise, y_t and x_t are the stock returns of country y and x in period t, and σ_{y_1} is the standard deviation of the stock market returns of country y in the tranquil period. Because the stock returns are scaled by their tranquil period standard deviations, $\hat{\gamma}_3$ is equal to the Forbes and Rigobon (2002) unconditional correlation coefficient. This means that testing the hypothesis $H_0 : \gamma_3 \leq 0$, $H_A : \gamma_3 > 0$ provides the same correlation test proposed by Forbes and Rigobon (2002).

Notice that for each country the stock returns over the full sample are divided by their respective standard deviation in the *tranquil* period. As stated above, this is done so that $\hat{\gamma}_3$ is equivalent to the unconditional correlation coefficient proposed by Forbes and Rigobon (2002). However, in a regression framework, scaling the variables by a constant will not change the significance of a coefficient, so the results of this test will not change if this modification is omitted. The regression approach is a convenient specification because it clearly illustrates the assumption that x_t is assumed to be exogenous in the model. While this assumption may be appropriate in the case where the source of the crisis can be properly identified, it would be inappropriate in crises of unknown origin. Consider the multivariate specification of Equation 1, where the scaling has been omitted:

$$\begin{aligned} y_t &= \gamma_0 + \gamma_1 d_t + \gamma_2 x_t + \gamma_3 x_t d_t + \eta_t \\ x_t &= \alpha_0 + \alpha_1 d_t + \alpha_2 y_t + \alpha_3 y_t d_t + \mu_t \end{aligned} \tag{2}$$

In this case the Forbes and Rigobon (2002) test, in either the regression or unconditional correlation form, is not suitable because it ignores the simultaneous nature of the stock returns. It can also be shown that the Forbes and Rigobon (2002) approach does not accurately correct for heteroskedasticity if Equation 1 suffers from omitted variable bias. When this occurs the bias cannot be corrected for because the unconditional correlation coefficient will either over- or under-correct for the heteroskedasticity, depending on the proportion of the heteroskedasticity originating from the omitted variables, which is not generally known.

Hence, while the modified correlation coefficient proposed by Forbes and Rigobon (2002) accounts for the bias due to heteroskedasticity, it is still prone to omitted variable bias and endogeneity problems. To account for this, Rigobon (2003) proposes a test based on the Determinant of the Change in the Covariance matrix (DCC), which controls for heteroskedasticity, omitted variables and endogeneity. This method estimates a covariance matrix over the tranquil and crisis periods, and then computes the determinant of the difference. Formally, the DCC statistic is computed as:

$$DCC = \frac{|\hat{\Omega}_c - \hat{\Omega}_n|}{\hat{\sigma}_{DCC}} \tag{3}$$

where $\hat{\Omega}_c$ and $\hat{\Omega}_n$ are the estimated covariance matrices in the crisis and normal periods, respectively, and $\hat{\sigma}_{DCC}$ is the estimated standard error of the DCC statistic.

However, this approach can be criticized on two grounds. First, the DCC statistic is significantly different from zero when either the correlation coefficients change or all of the shocks exhibit heteroskedasticity. This requires the assumption that at least one shock is homoskedastistic, which may not be the case. As Billio and Pelizzon (2003) show, this result is especially prevalent in the multivariate case where a large set of markets is considered. Second, both the Forbes and Rigobon (2002) and Rigobon (2003) tests are based on splitting the sample into large non-crisis periods and relatively small crisis periods. For example, Rigobon (2003) considers crisis periods as short as only a few weeks, while the non-crisis periods are typically at least several months in length. Dungey and Zhumabekova (2001) show that tests of this nature have very low power. As a result, these methods are too conservative and consistently under-reject the null hypothesis of stable transmission mechanisms or no contagion. Furthermore, both of these methods are frequently criticized for their sensitivity to the choice of crisis dates, which are chosen *ad hoc* by the researcher. Again, this point is illustrated by Dungey and Zhumabekova (2001) who find many more cases of contagion using the Forbes and Rigobon (2002) methodology when the crisis period is extended.

More recent works, such as Caporale et al. (2005) and Morales and Andreosso-O'Callaghan (2014), have focussed on developing models based on regression frameworks which control for heteroskedasticity by incorporating parametric GARCH structures into the error terms. Caporale et al. (2005) estimate the following model:

$$\begin{aligned} y_t &= \alpha_0 x_t + \alpha_1 d_{1t} x_t + z_t + \epsilon_{y_t} \\ x_t &= \beta_0 y_t + \beta_1 d_{2t} y_t + \gamma z_t + \epsilon_{x_t} \end{aligned} \tag{4}$$

$$\begin{aligned} h_{y_t} &= (1 - \delta_1 - \delta_2) + \delta_1 h_{y_{t-1}} + \delta_2 \epsilon^2_{y_{t-1}} \\ h_{x_t} &= (1 - \delta_3 - \delta_4) + \delta_3 h_{x_{t-1}} + \delta_4 \epsilon^2_{x_{t-1}} \end{aligned} \tag{5}$$

where y_{it} represents the return of the stock market index for country i in period t, z_t denotes a common shock and d_{it} is a dummy variable allowing for a break in the interdependence structure between the two countries. The authors estimate the break dates, when d_{it} changes from zero to one, endogenously by a sequential dummy test and argue that if the estimated coefficients, $\hat{\alpha}_1$ or $\hat{\beta}_1$, are significant, then contagion is present. The common shock is included to control for omitted variables which, if not accounted for, could lead to spurious results. Suppose that a crisis is caused by a global shock which is not controlled for in the model. Then movement in y_t may appear to be more correlated with x_t during a crisis, even though both are actually correlated with the common shock. Using this framework Caporale et al. (2005) find evidence of contagion between most country pairs during the Asian crisis. The results of the endogenous break test support earlier studies that suggest contagion began to occur after the collapse of the Hong Kong stock market, with only a few cases coinciding with the earlier devaluation of the Thai baht.

It is important to note a fundamental difference between this test and earlier methods that follow the definition of contagion proposed by Claessens et al. (2000).

Consider Figure 2, which shows the correlation between two markets over time. As depicted in the diagram, the two countries start out with a modest degree of interdependence. At T2 they enter a contagious period, which is terminated at T4 when the countries enter a third interdependence relationship. Traditionally, contagion tests have assumed that the start of the crisis period coincides exactly with the break in the interdependence structure, T2 on the figure below. However, as Baek and Jun (2011) point out, contagion may take time to surface. Suppose that the crisis occurs at T1, before the break in the interdependence structure. Then, traditional tests would produce biased estimates by splitting the sample at T1 when the true break is at T2. Here, Caporale et al. (2005) avoid this problem by endogenously testing for a structural break in the interdependence structure between two countries, rather than testing for the start of the crisis itself.

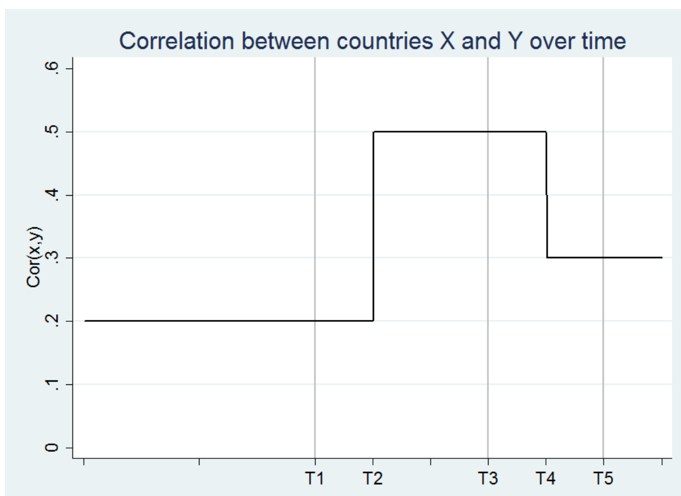


Figure 2. Pitfalls of crisis and contagion definitions.

Although subtle, this is an important departure from earlier tests. Again, recalling the definition put forth by Claessens et al. (2000), contagion is considered to be a break in the interdependence structure between two countries *after* a shock. While most of the earlier literature has implicitly assumed that contagion should occur coincident with a financial shock, this framework is more flexible in allowing for a period of delay while still according with the working definition of contagion. At this point it seems prudent to distinguish between the terms "crisis dates", which will refer to the period of high volatility in a particular source country, and "contagion dates", which will refer to the start and end of the break in the interdependence structure between a pair of countries, one of which being the source country itself. Then, Caporale et al. (2005) separate themselves from the rest of the literature by searching for contagion dates, rather than crisis dates.

However, while this method offers an alternative to the heteroskedasticity correction proposed in Forbes and Rigobon (2002), this comes with the parametric assumption imposed on the variance. Furthermore, it likely suffers from omitted variable bias. This is because Equation 4 only allows the stock market returns of country y to depend on the current stock returns of country x and a common shock. The approach taken by most other contagion studies is to first filter the stock returns to remove any serial correlation or country-specific effects. A test for contagion can then be performed using the residuals of each country's filtered returns. Consider the following:

$$\mu_{1t} = \psi_0 + \psi_1 d_{1t} + \psi_2 \mu_{2,t-1} d_{1t} + \eta_t \tag{6}$$

where $\mu_{i,t}$ denotes the residuals of the filtered asset returns for country i in period t. This is the residual test proposed by Morales and Andreosso-O'Callaghan (2014). Analyzing the 2007 financial crisis, their findings suggest that contagion spread from the United States to most countries in the Americas, and much of Europe, but was relatively scarce in Africa, Asia, and the Middle East.

In their test, the authors filter the asset returns using an AR(1)-GARCH(1,1) model. One issue with this framework is that it fails to filter out any of the interdependence between a given pair of countries. As a result, these effects show up in the residuals, implying that μ_1 and μ_2 will be correlated even in tranquil periods. This is problematic given that Equation 6 does not allow for any correlation in tranquil periods. Hence, this test likely over-rejects the null hypothesis of no contagion. The authors present a second model which adds the residuals of regional stock market returns in the crisis period to Equation 6, but this fails to address the issue. Instead, an improved approach would allow for a relationship between the residuals during non-crisis periods in Equation 6. The Morales and Andreosso-O'Callaghan (2014) methodology also fails to include any measure of global economic conditions, such as the common shock used in Caporale et al. (2005), an omission that potentially deepens the omitted variable bias. Common instruments to account for global economic conditions are interest rates[2] or a global composite index.[3]

As shown in Dungey and Zhumabekova (2001) and Mierau and Mink (2013), traditional contagion tests, such as Forbes and Rigobon (2002), are highly sensitive to the choice of crisis dates. Indeed, Mierau and Mink (2013) show that modifying the crisis dates can completely reverse the results of these tests. Furthermore, there is no reason to suggest that the crisis dates should coincide with the contagion dates, as illustrated in Figure 2, and implied in Caporale et al. (2005). This motivates the use of endogenous methods to identify the contagion dates, so that the windows are determined objectively from the data. This is especially important, although often overlooked in empirical work, for choosing the end date of the contagious period. As Dungey and Zhumabekova (2001) show, simply extending the sample period without changing the crisis date can completely change the results of correlation based tests. Again, this problem is clearly illustrated in Figure 2. Continuing to assume that the crisis occurs at T1 and the contagious period lasts from T2 to T4, Forbes and Rigobon (2002) is often criticized for placing the end of the sample at T3, too close to the start of the contagious period.

Indeed, even studies that allow the sample to increase to T5 are still assuming that the end of the contagious period is coincident with both the end of the crisis as well as

[2] See Forbes and Rigobon (2002) and Dungey et al. (2010) who use the short-term U.S. interest rate

[3] See Mierau and Mink (2013) who use the MSCI world index

the end of the sample. Ideally, both the start and end of the interdependence structure should be selected from a large enough sample to include the entire crisis episode. This would allow no assumptions to be made as to the timing of the contagion in relation to the crisis dates, and also allow for the pre- and post-crisis interdependence to differ. Hence, methods such as Caporale et al. (2005) which employ endogenous break tests capable of selecting only a single break, are not ideal. Gębka and Karoglou (2013) circumvent this limitation by employing an algorithm developed in Karoglou (2010), which modifies single break tests into multiple break tests. Using this method, the authors estimate pairwise breaks in the interdependence structures between Germany, France, Italy, the Netherlands, and the United Kingdom, finding between five and seven distinct periods in each case. Importantly, this method estimates both the start and end of each period, which solves the sample selection problem encountered by many other studies.

Another approach, rather than utilizing the algorithm proposed by Karoglou (2010), is to employ a test capable of detecting more than a single break. Both Guesmi et al. (2013) and Baek and Jun (2011) use the Bai and Perron (1998) method, which chooses the structural breaks to minimize the sum of squared residuals over the entire sample period. Guesmi et al. (2013) use this method to date the start of the 2007 financial crisis, finding the optimal date to be October 10, 2007, consistent with historical accounts. Baek and Jun (2011) take this approach even further by dating both the start and end dates of the 1997 Asian financial crisis. As mentioned, an important advantage of this approach is that it allows for contagion to be estimated over the entire crisis period. While several earlier studies have incorporated endogenous methods to choose the start date of a crisis, in most cases the end date is still chosen arbitrarily. Baek and Jun (2011) improve upon these works by endogenously estimating the entire contagious period to achieve the most unbiased sample.

This paper will contribute to the contagion literature in two ways. First, it will propose a modification to the recent work by Morales and Andreosso-O'Callaghan (2014) to better account for omitted variable bias. In particular, it will modify the filtering of stock returns to allow for global shocks, and adjust the contagion test to better capture the interdependence effects during non-crisis periods. Second, this paper will use the Bai and Perron (2003a) method of endogenously selecting break points to choose the start and end dates of the contagion. While the use of endogenous break tests is not new to the contagion literature[4], the most common methods are only concerned with identifying the start of the crisis window. The Bai and Perron (2003a) method is capable of selecting multiple breaks which allows for both the start and end dates of the contagious period to be estimated. Hence, the entire episode can be estimated endogenously. Finally, since this paper is concerned with estimating the contagion end date it introduces a new post-contagious period not considered in other studies. Rather than assuming that after the crisis has terminated the interdependence structure returns to normal, this paper will test to see whether countries return to their initial interdependence structure or achieve a new equilibrium.

3 Data and Methodology

This paper extends the AR(1)-GARCH(1,1) methodology employed by Morales and Andreosso-O'Callaghan (2014), showing that their initial specification consistently over-estimates the cases of contagion. We apply this methodology to two crises: the 2007 financial crisis, where the United States is considered the source country; and the 1997 Asian crisis, where both Hong Kong and Thailand are considered as sources. Analyzing these two crises allows for a comparison of how the proposed modifications affect the contagion tests in different time periods. While most studies consider contagion resulting from either Hong Kong or Thailand, this is usually done only because

[4] See Caporale et al. (2005), Gębka and Karoglou (2013), and Guesmi et al. (2013), for example.

a single source is needed to date the beginning of the crisis. Since I am endogenously dating breaks in the interdependence structure, this is not necessary. Also, testing both countries allows us to see how contagion spreads from relatively large and small markets, holding the time period constant. The first modification incorporates a variable into the stock market return filter to control for global economic conditions. Specifically, I estimate the following model:

$$y_{i,t} = \delta_0 + \delta_1 y_{i,t-1} + \gamma z_t + \epsilon_{i,t} \tag{7}$$

$$h_{i,t} = (1 - \alpha_1 - \alpha_2) + \alpha_1 h_{i,t-1} + \alpha_2 \epsilon^2_{i,t-1} \tag{8}$$

where $y_{i,t}$ is the stock market return for country i, and z_t represents global shocks. The inclusion of GARCH(1,1) error terms controls for heteroskedasticity, while the global shock reduces the bias from omitted variables, which could lead to spurious results. Intuitively, this system is intended to filter out any country specific effects, common factors, and auto-correlation, leaving the interdependence between the stock returns. Having estimated this model for a given pair of countries, the contagion test can then be carried out on the standardized GARCH(1,1) residuals, computed as $\hat{\mu}_{i,t} = \frac{\hat{\epsilon}_{i,t}}{\hat{\sigma}_{i,t}}$. Following the literature, I include interest rates as a proxy for global shocks. While this controls for some of the omitted variable problems, it may also lead to under-rejection of the null hypothesis of stable interdependence structures. This would occur if contagion is actually transmitted through the interest rate itself. Hence, I also estimate Equation 7 without the global shocks. The contagion equation is given by:

$$\mu_{i,t} = \varphi_0 + \varphi_1 d_t + \theta_2 \mu_{c,t} + \theta_3 \mu_{c,t} d_t + \eta_t \tag{9}$$

where $\mu_{i,t}$ and $\mu_{c,t}$ are the standardized GARCH(1,1) residuals for country i and the contagious country, and d_t is a dummy variable equal to one during contagious periods and zero otherwise. The contagion test amounts to testing the hypothesis $H_0 : \theta_3 \leq$

$0, H_A : \theta_3 > 0$. Notice that the null hypothesis of no contagion is only rejected if $\hat{\theta}_3$ is significantly greater than zero. This is because contagion is specifically defined as an increase in the correlation between two markets, as per Claessens et al. (2000). Again, the intuition behind Equation 9 is straightforward. Since the interdependence between the two countries was not removed with the estimation of Equation 7, the market relationship between the two countries is still present in the residuals. Hence, if $\hat{\theta}_3$ is significantly greater than zero, we can conclude that contagion is present. Importantly, while Equation 9 includes the estimation of a structural break, Equation 7, which filters the asset returns, does not. This is permissible because I am only testing to see if the interdependence structure between the two countries changes, as implied by the working definition of contagion. The relationships between an asset and its own past values or the global shock are assumed to be stable and can be estimated through the break.

Endogenously estimating the end date of the contagion period requires that the sample extend well beyond the crisis period itself. Hence, a product of estimating two structural breaks is that there are three periods under analysis: pre-contagion, contagion, and post-contagion. Since most other studies do not endogenously date the end of the crisis, they only consider the first two of these periods. This modification sets the methodology proposed in this paper apart from the rest of the literature, because Equation 9 assumes that the interdependence structure between a pair of countries is the same in the pre-contagion and post-contagion stages. Again, this comes from the fact that most contagion studies do not consider any post-crisis period at all. However, this framework is flexible enough to allow us to relax this assumption by including another dummy variable in the post-contagion period. Thus, I also consider the possibility that the interdependence structure is not only different in the contagious period, but also differs between the pre- and post-contagion periods. In other words, rather than the interdependence structure returning to normal, the countries reach a "new normal" after the crisis. Allowing this modification, the contagion equation now becomes:

$$\mu_{i,t} = \varphi_0 + \varphi_1 d_t + \theta_2 \mu_{c,t} + \theta_3 \mu_{c,t} d_t + \theta_4 \mu_{c,t} d1_t + \eta_t \tag{10}$$

where $d1_t$ is a dummy variable equal to one in the post-contagion period and zero otherwise. The test for a change in the interdependence structure is given by $H_0 : \theta_4 = 0, H_A : \theta_4 \neq 0$. To choose the contagion dates we estimate Equation 10 using the endogenous break test proposed by Bai and Perron (1998), which finds the optimal partitions to minimize the total sum of squared residuals. Consider the following matrix representation of Equation 10, modified to allow for structural breaks in the parameters:

$$\mu_{i,t} = X_t \beta_j + \eta_t \quad for \quad t = T_{j-1} + 1, ..., T_j \quad and \quad j = 1, ..., m+1 \ , \tag{11}$$

where $\mu_{i,t}$ is the standardized GARCH(1,1) residual of country i at time t, X_t is the vector of regressors containing a constant and $\mu_{c,t}$, β_j is the vector of coefficients for the two regressors in period j, and η_t denotes the error term. Note also that $j = m+1$ where j is the number of periods and m the number of breaks and, by convention, $T_0 = 0$ and $T_{m+1} = T$. Then, the optimal break dates solve the following:

$$SSR(T_{m,T}) = \min_{mh \leq j \leq T-h} [SSR(T_{m-1,j}) + SSR(j+1, T)] \tag{12}$$

where h is the minimum window size. Here the break dates are treated as unknowns and estimated at the same time as the β coefficients. More commonly, the window size is specified as a fraction of the total sample size. In this case, it is referred to as the trimming parameter and defined as $\xi = h/T$, so that each partition must be a fraction of the total sample size no smaller than ξ. We can then define break fractions as $\lambda_i = T_i/T$ where $0 < \lambda_1 < \cdots < \lambda_m$ and λ_i denotes the break fraction of the i_{th} partition. The break dates are required to be asymptotically distinct and bounded from the start and end of the sample such that, for some arbitrary ξ:

$$\Lambda_\xi = \{(\lambda_1, ..., \lambda_m); |\lambda_{i+1} - \lambda_i| \geq \xi, \lambda_1 \geq \xi, \lambda_m \leq 1 - \xi\}$$

In practice, this method is carried out by computing the sum of squared residuals for all possible combinations of start and end dates, for a given window size and number of breaks. These combinations are then compared to determine the optimal partitions. A major component of this paper involved writing a new program capable of implementing this structural break test in Stata. The program utilizes the recursive least squares algorithm described in Brown et al. (1975) to construct a matrix of the sum of squared residuals. It then iterates over the stored results for the combination that minimizes the global sum of squares, while computing the critical values for the F(ℓ | ℓ +1) test described in Bai and Perron (1998). The use of recursive residuals significantly reduces the number of matrix inversions the program needs to compute, making it absolutely essential to the practical implementation of this technique. Since the recursive algorithm itself is not available in Stata's existing commands, this portion of the code was written as a function in Mata, Stata's programming language. The program is technically capable of detecting up to five breaks for trim parameters of 0.05, 0.1, 0.15, 0.2, or 0.25. However, since the number of computations increases rapidly with the number of breaks and observations, anything beyond two breaks is not practical for the sample sizes considered in this paper. A more complete description of this method is contained in Bai and Perron (2003a).

As Baek and Jun (2011) and Bai and Perron (2003a) point out, one advantage of this framework is that it allows for breaks in the variance as well as the conditional mean. This is especially advantageous in the context of financial contagion since one would expect crises to be characterized by greater volatility and hence higher variance. The choice of trim parameter also plays a significant role in the results since this determines the minimum distance between two break points. If the trim parameter is chosen too large then the test will return break dates that are artificially far apart with potentially neither according with a true break. Conversely, Bai and Perron (2003b) note that small trim parameters can result in size distortions when the variance is permitted to vary across sub-sets, since estimates are based on fewer observations. Hence, there is a trade-off between choosing a trim parameter large enough to avoid size distortions yet small enough to accommodate crises of relatively short duration.

A more elaborate contagion test would extend the Caporale et al. (2005) test to a multivariate GARCH specification, as done in Dungey et al. (2010), so that contagion effects between all countries could be estimated simultaneously. Not only would this control for both the heteroskedasticity and endogeneity problems plaguing contagion tests, it would also allow a greater understanding of how crises spread after the source country infects a first set of markets. Specifically, while the test proposed in this paper is capable of detecting an initial spread of turmoil from a source country to another market, a multivariate specification would be capable of testing whether the crisis then spread from this newly infected country to a third market, and so on.

However, the practical implementation of a multivariate GARCH would restrict any empirical study to relatively few countries. This limits studies utilizing this framework to mostly regional analyses. Furthermore, such a framework is not compatible with the Bai and Perron (2003a) test, which is limited to single equation models. Hence, while the methodology outlined in this section controls for heteroskedasticity well, it may still be subject to endogeneity issues. Since this paper is primarily concerned with detecting the initial spread of contagion, this is only of concern for crises without a well defined starting point, such as the Asian crisis, where both Thailand and Hong Kong could be considered source countries. As mentioned in Section 2, testing for contagion from Thailand to Hong Kong and then turning around to estimate contagion from Hong Kong to Thailand ignores the simultaneous nature of the problem. To avoid such a problem, when testing for contagion originating from Hong Kong, I remove Thailand from the sample, and vice versa.

The sample data consists of the daily closing price of the leading stock indices for 36 countries for the 2007 crisis and 30 countries for the Asian financial crisis. A full list of these countries and their respective indices is included in Appendix A. All data is from Bloomberg. We consider sample periods of January 1, 1995 to December 31, 1999 for the Asian crisis and January 1, 2005 to December 31, 2011 for the 2007 crisis. Stock returns are calculated as the difference of logged prices, which are deemed stationary by the Augmented Dickey-Fuller and Phillips-Perron unit root tests. To account for global shocks I include the 3-month interest rate on U.S. Treasury bills in the asset filter. After filtering the stock returns for each period through the AR(1)-GARCH(1,1) model, with and without the global shock, ARCH-LM tests are performed on the standardized residuals, that is $\hat{\mu}_{i,t} = \frac{\hat{\epsilon}_{i,t}}{\hat{\sigma}_{i,t}}$, to ensure all ARCH effects have been removed from the data. All series fail to reject the null hypothesis of no ARCH effects at the 1% significance level, and only a handful reject at the 5% significance level. With this result, and to stay consistent with Caporale et al. (2005) and Morales and Andreosso-O'Callaghan (2014), I follow the GARCH(1,1) specification. The full results of these tests are reported in Appendix B.

To control for the fact that markets in different countries are open at different times of the day, I follow Forbes and Rigobon (2002) and use rolling average two-day returns. Returns are calculated in local currency as the difference between logged prices, and not converted into U.S. dollars as is common in the literature. The usual argument in favour of converting stock returns into a common currency is that, since contagion is often thought to be a product of foreign investors simultaneously divesting in a particular market, it is natural to take their perspective and convert returns into their own currency. However, as Mierau and Mink (2013) observe, "[...] if two non-synchronous stock market returns are converted into a common currency and both currencies simultaneously depreciate or appreciate against this common currency, the stock market returns would seem to be synchronous while in reality they are not"(Mierau and Mink, 2013, p.4768). While Mink (2009) also shows that this distinction can matter empirically, other studies such as Baek and Jun (2011) that use both local and U.S. dollar returns, find that there is little difference between the results. However, given that the 2007 crisis saw many currencies fluctuate as a result of investors' flight to quality, I will focus on local currencies to avoid any spurious relationships.

4 Results

4.1 2007 Financial Crisis

The 2007 financial crisis is rooted in the bursting of the United States housing bubble in mid-2007. The bubble itself was largely a product of both the low interest rate environment and a shift in the banking sector to pool, tranche, and re-distribute loans rather than hold them until maturation. As Brunnermeier (2009) observes, the latter factor led to a fall in lending standards as banks only carried default risk until mortgages were repackaged and moved on. By mid-2007, however, mortgage defaults in the United States were on the rise, causing the price of mortgage-backed securities to plummet. Since these products were routinely used as collateral, their rapid devaluation spread quickly across financial markets, ultimately triggering the 2007 crisis.

Figure 3 shows the United States stock market returns over the sample period, which consists of daily data from January 1, 2005 to December 31, 2011. Clearly, although the crisis is considered to have started in 2007, stock markets were their most volatile in 2008 and 2009. Crises are most often characterized as periods of negative returns and high volatility. While the former are of course detrimental to investors, the latter establish a period of uncertainty and unpredictability that is most often associated with crises. Hence, to provide a benchmark for the dates established in the contagion tests, I first consider dating the crisis itself using the Bai and Perron (2003a) test. To accomplish this I fit a simple intercept-only model to the standard deviation of United States stock returns.

This method suggests that the crisis began September 12, 2008 and lasted until May 26, 2009. As mentioned, the Bai and Perron (2003a) method requires a trim parameter for asymptotic purposes such that each partition is at least this fraction of the total sample. If the trim parameter selected is too large it will force the test to estimate a crisis period greater than the optimal length. If the trim parameter is allowed to become too small, however, estimates are based on fewer observations which could lead to size distortions. In this case, a trim parameter of 5% was used over a sample of 7 years, meaning that the crisis is restricted to being a minimum of 91 daily observations. This implies that each partition must be approximately four months long, so small sample selection is not considered to be an issue.

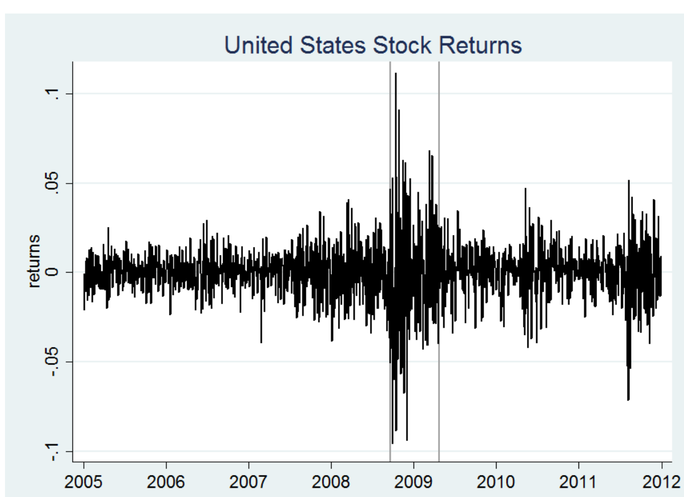


Figure 3. United States stock returns with crisis dates.

Table 3 shows the results for the three different contagion tests at conventional significance levels, without the global shock included in the filter. In each case, the contagious country is the United States. The restricted contagion test shows the results for Equation 9, where the interdependence structure is assumed to be the same in the pre- and post-contagion periods. The unrestricted contagion test shows the results for Equation 10, where the interdependence structure is allowed to vary in all three periods. Finally, the third test shows the results of the Morales and Andreosso-O'Callaghan (2014) test.

Clearly from these results the Morales and Andreosso-O'Callaghan (2014) test significantly overestimates the presence of contagion, finding positive results for contagion originating in the United States to all but nine countries. Comparatively, the restricted and unrestricted tests find contagion in less than half of the sample and have smaller contagion coefficients in virtually every case. As mentioned, this discrepancy occurs because the normal interdependence between the pair of countries is not properly filtered out in the Morales and Andreosso-O'Callaghan (2014) test. Hence, the contagion coefficient is artificially high because it is actually measuring interdependence during the crisis period rather than contagion *per se*. Indeed, not only do the modified tests indicate fewer cases of contagion, they find many more negative coefficients, suggesting that some economies are actually *less* correlated during crisis periods. The difference between the results of the restricted test and the Morales and Andreosso-O'Callaghan (2014) test are the most striking: the restricted test fails to reject the null hypothesis of no contagion in 27 cases and returns negative coefficients for 26 of those countries, compared to the Morales and Andreosso-O'Callaghan (2014) test which fails to reject the null hypothesis nine times of which only four have negative coefficients.

Table 3: Contagion originating in the United States, without a global shock

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
Canada	N	-0.477	1.000	N	-0.404	1.000	Y	0.232	0.026
Finland	N	-0.172	0.995	N	-0.102	0.915	Y	0.368	0.000
France	N	-0.093	0.985	N	0.043	0.205	Y	0.554	0.000
Germany	N	-0.208	1.000	N	-0.094	0.948	Y	0.455	0.000
Ireland	N	-0.014	0.619	Y	0.174	0.002	Y	0.478	0.000
Italy	N	-0.295	0.995	N	-0.264	0.986	Y	0.249	0.029
The Netherlands	N	-0.123	0.974	N	-0.021	0.622	Y	0.502	0.000
Spain	Y	0.246	0.000	Y	0.286	0.000	Y	0.773	0.000
Denmark	N	-0.016	0.595	Y	0.134	0.035	Y	0.453	0.000
Norway	N	-0.416	1.000	N	-0.236	0.987	N	0.065	0.285
Slovakia	N	-0.065	0.866	N	0.058	0.195	Y	0.495	0.000
Switzerland	N	-0.035	0.775	Y	0.122	0.018	Y	0.521	0.000
The United Kingdom	N	-0.106	0.995	Y	0.142	0.015	Y	0.523	0.000
Australia	N	-0.358	1.000	N	-0.302	0.996	N	-0.072	0.840
Japan	N	-0.214	0.971	N	-0.140	0.879	N	0.025	0.414
New Zealand	Y	0.241	0.002	Y	0.331	0.000	Y	0.328	0.000
Belgium	N	-0.042	0.842	Y	0.227	0.000	Y	0.538	0.000
Hong Kong	N	-0.232	0.988	N	-0.157	0.930	N	0.030	0.385
Korea	Y	0.197	0.021	Y	0.295	0.003	Y	0.427	0.000
Indonesia	N	-0.339	0.998	N	-0.207	0.943	N	-0.148	0.894
Malaysia	Y	0.557	0.000	Y	0.731	0.000	Y	0.711	0.000
Singapore	N	-0.042	0.761	N	0.060	0.185	Y	0.235	0.000
Thailand	Y	0.201	0.007	Y	0.259	0.001	Y	0.353	0.000
Taiwan	N	0.036	0.358	N	0.125	0.113	Y	0.253	0.004
Philippines	Y	0.309	0.003	Y	0.453	0.000	Y	0.416	0.000
Argentina	N	-0.403	1.000	N	-0.292	1.000	Y	0.257	0.001
China	N	-0.322	1.000	N	-0.250	0.997	N	-0.204	0.994
India	N	-0.224	0.997	N	-0.139	0.940	N	0.027	0.366
Russia	N	-0.178	1.000	Y	0.322	0.001	Y	0.245	0.000
South Africa	N	-0.110	0.968	N	0.105	0.069	Y	0.306	0.000
Brazil	Y	0.206	0.000	Y	0.190	0.000	Y	0.846	0.000
Chile	N	-0.376	1.000	N	-0.366	1.000	N	0.196	0.050
Mexico	Y	0.230	0.000	Y	0.335	0.000	Y	0.793	0.000
Iceland	N	-0.646	1.000	N	-0.687	1.000	N	-0.562	1.000
Turkey	N	-0.344	1.000	N	-0.518	1.000	Y	0.112	0.029

P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

The importance of allowing the pre- and post-contagion interdependence structures to differ is also evident from Table 3. Not only does the unrestricted test find significantly more cases of contagion compared to the restricted version, it also finds far fewer negative contagion coefficients. This indicates that the coefficients presented by the restricted test are biased downward because the model is forcing the interdependence structure to be the same in each period. Indeed, in all but three cases - Iceland, Turkey, and Brazil - the unrestricted test has a higher contagion coefficient than the restricted.

Table 4 displays the results of the same three tests but with the filter modified to include a global shock, in this case the U.S. short-term interest rate. Again, the discrepancy between the Morales and Andreosso-O'Callaghan (2014) test and the two corrections proposed in this paper is evident. The results are similar to those in Table 3, where a global shock was not included: the Morales and Andreosso-O'Callaghan (2014) test suggests that contagion is present for almost the entire sample while the modified tests find contagion in only nine cases for the restricted test and 18 cases for the unrestricted test. The outcome of the results also appears to be fairly consistent between the two alternative filters: the restricted, unrestricted, and Morales and Andreosso-O'Callaghan (2014) tests have one, four and three more rejections of the null hypothesis, respectively.

Comparing the estimated contagion coefficients in Tables 3 and 4 also shows that, in general, the estimated contagion coefficients are quite close and do not substantially change when the global shock is added to the model. However, while the discrepancy is generally small, in absolute magnitude the coefficients for all three tests are larger in most cases when a global shock is included.

Table 4: Contagion originating in the United States, with a global shock

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
Canada	N	-0.473	1.000	N	-0.393	1.000	Y	0.249	0.021
Finland	N	-0.162	0.991	N	-0.089	0.879	Y	0.391	0.000
France	N	-0.115	0.998	Y	0.105	0.049	Y	0.576	0.000
Germany	N	-0.218	1.000	N	-0.124	0.982	Y	0.477	0.000
Ireland	N	-0.016	0.627	Y	0.173	0.002	Y	0.500	0.000
Italy	N	-0.315	0.996	N	-0.271	0.987	Y	0.252	0.030
The Netherlands	N	-0.084	0.972	N	0.100	0.069	Y	0.569	0.000
Spain	Y	0.260	0.000	Y	0.296	0.000	Y	0.807	0.000
Denmark	N	-0.377	1.000	N	-0.256	0.974	N	0.141	0.058
Norway	N	-0.413	1.000	N	-0.230	0.983	N	0.083	0.239
Slovakia	N	-0.056	0.827	N	0.076	0.132	Y	0.514	0.000
Switzerland	N	-0.038	0.798	Y	0.207	0.001	Y	0.542	0.000
The United Kingdom	N	-0.055	0.882	Y	0.103	0.030	Y	0.560	0.000
Australia	N	-0.025	0.687	Y	0.190	0.003	Y	0.251	0.000
Japan	N	-0.148	0.994	N	-0.068	0.766	Y	0.143	0.003
New Zealand	Y	0.300	0.001	Y	0.391	0.000	Y	0.409	0.000
Belgium	N	-0.041	0.833	Y	0.244	0.000	Y	0.552	0.000
Hong Kong	N	-0.217	0.982	N	-0.141	0.905	N	0.063	0.274
Korea	N	-0.227	0.999	N	-0.248	0.985	N	0.072	0.137
Indonesia	N	-0.008	0.563	Y	0.135	0.024	Y	0.180	0.000
Malaysia	Y	0.598	0.000	Y	0.788	0.000	Y	0.779	0.000
Singapore	N	0.016	0.386	Y	0.187	0.003	Y	0.304	0.000
Thailand	Y	0.244	0.001	Y	0.295	0.000	Y	0.399	0.000
Taiwan	N	0.047	0.320	N	0.139	0.093	Y	0.283	0.002
Philippines	Y	0.323	0.001	Y	0.461	0.000	Y	0.443	0.000
Argentina	N	-0.399	1.000	N	-0.287	1.000	Y	0.273	0.001
China	N	-0.373	1.000	N	-0.309	0.999	N	-0.242	0.998
India	Y	0.278	0.000	Y	0.309	0.000	Y	0.466	0.000
Russia	N	-0.188	1.000	Y	0.305	0.001	Y	0.246	0.000
South Africa	N	-0.179	1.000	N	0.110	0.089	Y	0.293	0.000
Brazil	Y	0.225	0.000	Y	0.208	0.000	Y	0.868	0.000
Chile	N	-0.392	1.000	N	-0.381	1.000	N	0.184	0.079
Mexico	Y	0.244	0.000	Y	0.355	0.000	Y	0.814	0.000
Iceland	Y	0.232	0.000	Y	0.249	0.001	Y	0.315	0.000
Turkey	N	-0.351	1.000	N	-0.529	1.000	Y	0.120	0.021

P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

In light of the fact that the Morales and Andreosso-O'Callaghan (2014) test appears to be biased in favour of contagion, producing overwhelmingly positive results, and the restricted test appears biased against contagion, producing mostly negative contagion coefficients, I focus my analysis on the unrestricted test, which I consider to be the most appropriate measure of contagion. Regional effects do not appear significant: about half of European countries test positively for contagion, which is in line with Latin America. However, East Asian markets do seem to be more susceptible to contagion: Indonesia, Malaysia, Singapore, Thailand, and the Philippines all have significant contagion coefficients. Countries with large financial sectors, such as the United Kingdom, and Switzerland, also appear to be more susceptible to contagion.

Table 5 displays the estimated coefficients and P-values for θ_4, which allows the interdependence structure to vary pre- and post-contagion, with and without a global shock. A significant value indicates that the pair of countries exit from the crisis into a new interdependence structure, rather than returning to the pre-crisis relationship. The results of the contagion test are also included for easy comparison.

The table shows that in most cases $\hat{\theta}_4$ is statistically significant, indicating that these markets do not return to the old equilibrium after a crises but instead move to a new level of interdependence. These results are relatively consistent whether or not the global shock is included but are somewhat stronger without the global shock, which shows only five cases where $\hat{\theta}_4$ is not significant at conventional levels. Analyzing Table 5 shows that most of the cases where $\hat{\theta}_4$ is not significant coincide with countries that do not exhibit positive contagion effects. This is logical since, if the interdependence structure does not significantly change over the crisis period, then there is no "normal" relationship to return to because this relationship was never deviated from in the first place. However, the reverse is not in general true: significant estimates of θ_4 do not disproportionately coincide with cases of contagion. Another result to take away from Table 5 is that in most cases, whether significant or not, $\hat{\theta}_4$

takes a positive value, indicating that the countries become *more* correlated after a crisis compared to the pre-contagious period. Indeed, none of the negative coefficients for $\hat{\theta}_4$ are statistically significant.

Table 5: Test for significance of change in pre- and post-crisis interdependence, United States

Country	No Global Shock Contagion?	θ_4	P-value	Global shock Contagion?	θ_4	P-value
Canada	N	0.128	0.001	N	0.143	0.000
Finland	N	0.109	0.027	N	0.116	0.019
France	N	0.223	0.000	Y	0.289	0.000
Germany	N	0.174	0.000	N	0.142	0.004
Ireland	Y	0.292	0.000	Y	0.295	0.000
Italy	N	0.055	0.338	N	0.080	0.178
The Netherlands	N	0.160	0.000	N	0.227	0.000
Spain	Y	0.113	0.014	Y	0.104	0.031
Denmark	Y	0.224	0.000	N	0.127	0.247
Norway	N	0.317	0.000	N	0.324	0.000
Slovakia	N	0.182	0.000	N	0.198	0.000
Switzerland	Y	0.240	0.000	Y	0.320	0.000
The United Kingdom	Y	0.323	0.000	Y	0.268	0.000
Australia	N	0.062	0.501	Y	0.315	0.000
Japan	N	0.106	0.069	N	0.095	0.270
New Zealand	Y	0.144	0.010	Y	0.149	0.008
Belgium	Y	0.350	0.000	Y	0.374	0.000
Hong Kong	N	0.135	0.009	N	0.138	0.008
Korea	Y	0.129	0.031	N	-0.024	0.810
Indonesia	N	0.160	0.017	Y	0.217	0.001
Malaysia	Y	0.226	0.000	Y	0.247	0.000
Singapore	N	0.180	0.002	Y	0.266	0.000
Thailand	Y	0.119	0.026	Y	0.108	0.047
Taiwan	N	0.159	0.004	N	0.166	0.003
Philippines	Y	0.192	0.002	Y	0.186	0.002
Argentina	N	0.191	0.000	N	0.193	0.000
China	N	0.121	0.034	N	0.110	0.062
India	N	0.143	0.015	Y	0.078	0.211
Russia	Y	0.571	0.000	Y	0.566	0.000
South Africa	N	0.312	0.000	N	0.351	0.000
Brazil	Y	-0.040	0.376	Y	-0.042	0.363
Chile	N	0.063	0.315	N	0.072	0.264
Mexico	Y	0.155	0.009	Y	0.162	0.007
Iceland	N	-0.086	0.080	Y	0.027	0.676
Turkey	N	-0.181	0.183	N	-0.187	0.167

P-values are for the null hypothesis $H_0 : \theta_4 = 0$. The results of the corresponding contagion test are also included at the 95% significance level.

Table 6 shows the Bai and Perron (2003a) structural break dates outlining the contagious period with and without the global shock variable included in the filter. We consider the unrestricted test, which allows the interdependence in the pre- and post-contagion periods to vary, to be the most robust of the three tests and hence include the contagion results of this test at the 5% level for comparative purposes.

Table 6: Contagion dates, United States

Country	Contagion?	No Global Shock Start date	End date	Contagion?	Global Shock Start date	End date
Canada	N	Apr 17, 2008	Aug 26, 2008	N	Apr 17, 2008	Aug 26, 2008
Finland	N	Sep 27, 2007	Jul 16, 2008	N	Sep 27, 2007	Jul 16, 2008
France	N	Jun 1, 2007	Mar 27, 2009	Y	Mar 23, 2006	Mar 27, 2009
Germany	N	Jun 18, 2007	Sep 18, 2008	N	Apr 26, 2007	Sep 18, 2008
Ireland	Y	Feb 12, 2007	Mar 25, 2009	Y	Feb 12, 2007	Mar 24, 2009
Italy	N	Apr 26, 2007	Aug 6, 2007	N	Apr 26, 2007	Aug 6, 2007
The Netherlands	N	Oct 12, 2007	Jul 16, 2008	N	Mar 24, 2006	Jul 16, 2008
Spain	Y	Mar 26, 2009	Dec 8, 2009	Y	Mar 27, 2009	Dec 8, 2009
Denmark	Y	Jul 23, 2007	Jul 16, 2008	N	Jul 11, 2005	May 10, 2006
Norway	N	Apr 16, 2008	Aug 20, 2008	N	Apr 16, 2008	Aug 20, 2008
Slovakia	N	Jun 1, 2007	Jul 16, 2008	N	Jun 1, 2007	Jul 16, 2008
Switzerland	Y	Feb 23, 2007	Feb 27, 2009	Y	Apr 10, 2006	Feb 26, 2009
The United Kingdom	Y	Mar 24, 2006	Mar 27, 2009	Y	Jun 29, 2007	Mar 26, 2009
Australia	N	Oct 11, 2005	Oct 16, 2006	Y	Oct 16, 2006	Feb 5, 2009
Japan	N	Jun 21, 2007	Oct 23, 2007	N	Jan 30, 2006	Feb 5, 2008
New Zealand	Y	Nov 8, 2007	Jul 17, 2008	Y	Dec 7, 2007	Jul 17, 2008
Belgium	Y	Mar 22, 2006	Mar 20, 2009	Y	Mar 22, 2006	Mar 20, 2009
Hong Kong	N	Apr 29, 2008	Sep 18, 2008	N	Apr 29, 2008	Sep 18, 2008
Korea	Y	Dec 13, 2006	Jul 31, 2007	N	Sep 1, 2005	Dec 11, 2006
Indonesia	N	Jul 17, 2006	Dec 6, 2006	Y	Dec 6, 2006	Feb 3, 2009
Malaysia	Y	Dec 4, 2006	Apr 24, 2007	Y	Dec 6, 2006	Apr 24, 2007
Singapore	N	Oct 12, 2007	Mar 10, 2009	Y	Jan 24, 2007	Mar 10, 2009
Thailand	Y	Aug 15, 2008	Mar 2, 2009	Y	Aug 15, 2008	Apr 6, 2009
Taiwan	N	May 19, 2008	Oct 28, 2008	N	May 19, 2008	Oct 28, 2008
Philippines	Y	Feb 13, 2007	Jul 27, 2007	Y	Feb 13, 2007	Aug 16, 2007
Argentina	N	Dec 20, 2007	Aug 29, 2008	N	Dec 20, 2007	Aug 29, 2008
China	N	Jan 16, 2007	Sep 12, 2008	N	Jan 18, 2008	Sep 12, 2008
India	N	Nov 15, 2007	Sep 12, 2008	Y	Sep 12, 2008	Nov 23, 2009
Russia	Y	Oct 4, 2005	Aug 18, 2008	Y	Oct 4, 2005	Aug 14, 2008
South Africa	N	Feb 26, 2007	Jul 16, 2008	N	Feb 2, 2006	Jul 16, 2008
Brazil	Y	Sep 8, 2008	Nov 18, 2009	Y	Sep 8, 2008	Nov 18, 2009
Chile	N	Aug 16, 2010	Jan 27, 2011	N	Aug 16, 2010	Jan 27, 2011
Mexico	Y	May 11, 2006	Dec 10, 2009	Y	May 11, 2006	Oct 27, 2009
Iceland	N	Sep 29, 2008	Jan 30, 2009	Y	Jul 2, 2007	Sep 29, 2008
Turkey	N	May 6, 2005	Feb 12, 2007	N	May 6, 2005	Feb 13, 2007

The contagion dates are determined by the Bai and Perron (2003a) test using a 5% trim parameter. The results of the unrestricted contagion test, which allows the interdependence structures to change in the pre- and post-contagious periods, are also included at the 95% significance level.

A 5% trim parameter was used to accord with the dating of the crisis based on the standard deviation of returns of the United States stock index. Recall that this exercise determined that the crisis started on September 12, 2008 and lasted until May 26, 2009, a period of 256 days. By comparison, the average contagious period is 652 days with a global shock in the filter, and 578 days without. Malaysia has the shortest contagious period under both filters: 141 days without the shock and 139 days with. Comparatively, Mexico has contagious periods of 1265 and 1309 days with and without the filter, the largest among all countries. The first insight here is that contagious periods can last much longer than the crisis itself. We also notice that contagion in the East Asian period is, in general, well below average. This is especially true without the global shock, where the average case of contagion in the period is only 184 days. When the shock is added the average period in the region increases to 425 days, much larger but still more than 200 days below average. This increase is led mostly by the addition of Singapore and Indonesia, and removal of Korea from the list of contagious countries.

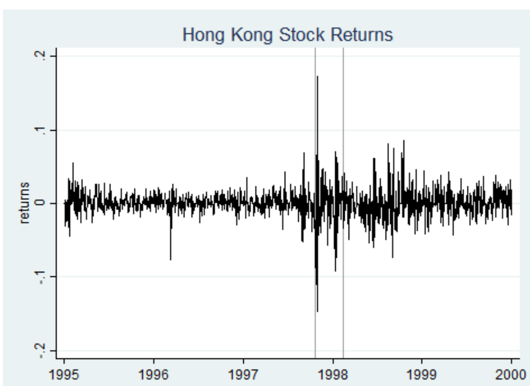
There are 12 countries that test positively for contagion under the unrestricted test both with and without the global shock: Ireland, Spain, Switzerland, the United Kingdom, New Zealand, Belgium, Malaysia, Thailand, the Philippines, Russia, Brazil, and Mexico. Of these, the structural breaks for Ireland, Spain, Belgium, Malaysia, Russia, and Brazil are very stable to the removal of the global shock. In each case the dates either stay the same or move by only a matter of days. New Zealand, Thailand, the Philippines, and Mexico show small changes ranging from a few weeks to just over one month long. This leaves only Switzerland and the United Kingdom as countries where the contagion dates change significantly when the global shock is added to the asset filter. For both countries the closing date is stable while the opening date varies between the two different filters. Interestingly, both opening dates are well before the crisis starting date of September 12, 2008 and move in opposite directions when the global shock is added to the filter.

In general, however, the contagion dates are quite consistent for cases testing positively for contagion under both filters. Again, this implies that the exclusion or inclusion of a global shock does not change the central results of the contagion test. One reason for this could be that this crisis originated in the United States. Since this economy is so large, the correlation between any global shock variable and the United States stock index would be quite high. This is especially true here because of the choice of instrument. Following the literature, I included the U.S. short-term interest rate, which itself was adjusted in response to the crisis. Hence, the additional explanatory power achieved from including the global shock in the model appears to be minimal.

Taking a closer look at the contagion dates themselves, of the 12 cases of contagion, four occur entirely before the beginning of the crisis period: New Zealand, Malaysia, the Philippines, and Russia. Of the remaining eight countries, all but Spain have contagion starting dates before the crisis period, although Brazil is only by a matter of days. These results seem to imply that, rather than an increase in correlation following a crisis, contagion most commonly begins to occur in the pre-crisis period. Again, this highlights the benefits of the Bai and Perron (2003a) framework which tests for the structural break itself rather than assuming a crisis date and then testing for a change in the interdependence structure. Tests based on the latter method may have detected contagion in these cases, but would have failed to observe that the structural break occurred before the crisis even began. As an example of this, between the two filters there are 70 pairs of contagion start and end dates: two for each country. Of these seventy dates, only one case, India with the global shock, tests positively for contagion and has a starting date coinciding exactly with the start of the crisis in the United States.

4.2 Asian Financial Crisis

The early 1990s was a period of economic boom for most East Asian economies. Recovering from an economic slump, the United States set short-term interest rates at their lowest level in decades. This low interest rate environment spurred foreign investment in East Asian countries as investors sought out higher returns. By 1997, however, confidence in the region began to wane, culminating in a speculative attack against the Thai baht in May 1997, leading to the eventual abandonment of its currency peg. The crisis quickly spread to the rest of the region: the Indonesian rupiah came under attack in August and rapidly depreciated against the U.S. dollar, and the Hong Kong stock market collapsed in October. Naturally, the speed with which the crisis spread throughout the region led many to worry about the contagious effects of the financial crisis. This is observable in the data: the NASDAQ dropped 7% on October 27, 1997, days after the Hong Kong stock market collapsed.



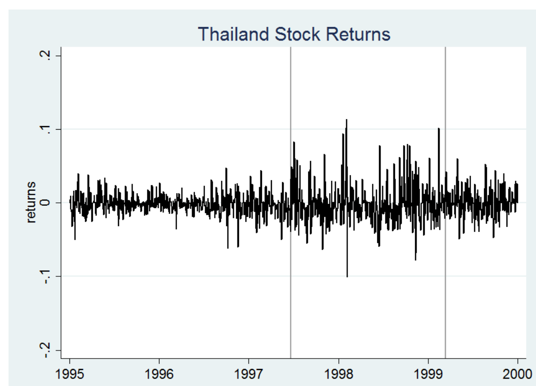


Figure 4: Hong Kong and Thailand stock returns with crisis dates

Figure 4 shows the stock returns of Hong Kong and Thailand over the sample period: January 1, 1995 to December 31, 1999. Consistent with historical events, stock returns in Thailand became increasingly volatile in the middle of 1997 followed by Hong Kong in October of that same year. The Bai and Perron (2003a) test on the standard deviation of stock returns finds the crisis dates of June 20, 1997 and March 12, 1999 in Thailand and October 22, 1997 to February 12, 1998 in Hong

Kong. These dates match historical events rather well: the Thai bhat abandoned its currency peg in July 1997 and the Hong Kong stock market collapsed in October of 1997. In this case the 5% trim parameter equals out to approximately 65 daily observations, meaning that each contagious period can be no less than approximately three months long. Again, this seems to be a sufficiently large number of observations so I do not consider small sample size an issue going forward.

Table 7 shows the results for the contagion tests originating from Hong Kong, without a global shock. Unavailability of data forced Denmark, Norway, New Zealand, Singapore, Russia, and South Africa to be removed from the sample. Notice that, since I will later test for contagion originating from Thailand, I do not include it in the tests for contagion originating from Hong Kong. This would lead to endogeneity issues, as mentioned in Section 2. When comparing the results of the three tests it is not as clear that the Morales and Andreosso-O'Callaghan (2014) test overestimates the cases of contagion, as was the case in the 2007 crisis. Here, the Morales and Andreosso-O'Callaghan (2014) test rejects the null hypothesis of no change in the interdependence structure for 21 countries, only one more case than the restricted and unrestricted tests.

A closer look at the estimated parameter values themselves, however, suggests that the bias is still present: for all countries but one the contagion coefficient is highest under the Morales and Andreosso-O'Callaghan (2014) test. The one exception here is Iceland, which has its highest coefficient under the unrestricted test. However, Iceland does not test positively for contagion under any of the tests. The similarity of the three tests here compared to the 2007 crisis is likely due to the degree of market integration of the Hong Kong economy, which is much smaller than that of the United States. Hence, I would expect that Hong Kong would be less correlated with other countries during tranquil times, and in many cases not significantly correlated at all. The bias from the Morales and Andreosso-O'Callaghan (2014) test should be much

Table 7: Contagion originating in Hong Kong, without a global shock

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
United States	N	-0.576	1.000	N	-0.635	1.000	N	-0.420	0.998
Canada	Y	0.253	0.000	Y	0.264	0.000	Y	0.403	0.000
Finland	Y	0.429	0.000	Y	0.521	0.000	Y	0.679	0.000
France	Y	0.251	0.000	Y	0.257	0.000	Y	0.391	0.000
Germany	Y	0.280	0.000	Y	0.258	0.000	Y	0.416	0.000
Ireland	Y	0.197	0.016	Y	0.212	0.013	Y	0.471	0.000
Italy	N	-0.519	1.000	N	-0.428	1.000	N	-0.296	0.992
The Netherlands	Y	0.364	0.000	Y	0.386	0.000	Y	0.626	0.000
Spain	Y	0.211	0.000	Y	0.202	0.000	Y	0.321	0.000
Slovakia	Y	0.257	0.000	Y	0.261	0.000	Y	0.432	0.000
Switzerland	Y	0.496	0.000	Y	0.562	0.000	Y	0.696	0.000
The United Kingdom	N	-0.485	1.000	N	-0.370	0.999	N	-0.151	0.898
Australia	Y	0.479	0.000	Y	0.527	0.000	Y	0.850	0.000
Japan	Y	0.197	0.015	Y	0.261	0.005	Y	0.479	0.000
Belgium	Y	0.242	0.000	Y	0.221	0.000	Y	0.424	0.000
Korea	Y	0.379	0.000	Y	0.396	0.000	Y	0.441	0.000
Indonesia	Y	0.434	0.000	Y	0.438	0.000	Y	0.723	0.000
Malaysia	N	-0.216	0.997	N	-0.267	0.999	Y	0.158	0.021
Taiwan	Y	0.231	0.000	Y	0.244	0.000	Y	0.359	0.000
Philippines	Y	0.272	0.000	Y	0.249	0.001	Y	0.525	0.000
Argentina	Y	0.257	0.000	Y	0.246	0.000	Y	0.369	0.000
China	Y	0.306	0.003	Y	0.286	0.005	Y	0.338	0.001
India	Y	0.484	0.000	Y	0.474	0.000	Y	0.554	0.000
Brazil	N	-0.449	0.999	N	-0.379	0.995	N	-0.275	0.972
Chile	N	-0.035	0.623	N	-0.013	0.545	N	0.127	0.119
Mexico	Y	0.224	0.000	Y	0.249	0.000	Y	0.303	0.000
Iceland	N	0.009	0.442	N	0.013	0.425	N	0.001	0.496
Turkey	N	-0.484	1.000	N	-0.489	1.000	N	-0.351	0.996

P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

smaller because in many cases there is no significant interdependence structure during tranquil times that needs to be controlled for in the regression.

While the overwhelmingly positive results indicate that most regions were significantly affected by contagion originating from Hong Kong, the East Asian countries seem to have been particularly vulnerable. Only Malaysia does not show signs of contagion during the crisis. Interestingly, Italy, which is the only country in which Forbes and Rigobon (2002) find evidence supporting contagion from Hong Kong during the Asian crisis, is one of the few countries not testing positive for contagion in any of the three tests.

Notably, the restricted and unrestricted tests indicate that there are far more cases of contagion compared to the 2007 crisis. This is likely due to the exclusion of the global shock variable. While this factor was not generally significant in the case of the 2007 crisis, I postulated that the reasons for this were likely the use of the U.S. short-term interest rate as an instrument, which responded quickly to the crisis, and the size of the American economy relative to the world economy. With Hong Kong being a much smaller market, the inclusion of the U.S. short-term interest rate as an instrument for global economic conditions is much more appropriate. Table 8 confirms this suspicion: when the global shock is added to the filter the number of cases of contagion falls for all three tests. This indicates that the omitted variable bias from not including a measure of global economic conditions may be more severe when considering crises originating in relatively small markets.

Table 9 shows that, in most cases, countries returned to their initial interdependence structure with Hong Kong after the crisis terminated. This is especially true for the East Asian countries, none of which have significant estimates of θ_4. As in the case of the 2007 crisis, there is also no evidence that changes in the interdependence structure are more common where contagion is detected.

Table 8: Contagion originating in Hong Kong, with a global shock

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
United States	N	-0.587	1.000	N	-0.644	1.000	N	-0.431	0.999
Canada	Y	0.264	0.000	Y	0.270	0.000	Y	0.408	0.000
Finland	Y	0.506	0.000	Y	0.592	0.000	Y	0.747	0.000
France	Y	0.356	0.000	Y	0.392	0.000	Y	0.579	0.000
Germany	Y	0.272	0.000	Y	0.257	0.000	Y	0.397	0.000
Ireland	Y	0.248	0.005	Y	0.261	0.004	Y	0.510	0.000
Italy	N	-0.465	1.000	N	-0.366	0.998	N	-0.250	0.981
The Netherlands	Y	0.396	0.000	Y	0.422	0.000	Y	0.649	0.000
Spain	Y	0.262	0.000	Y	0.274	0.000	Y	0.373	0.000
Slovakia	Y	0.489	0.000	Y	0.545	0.000	Y	0.710	0.000
Switzerland	Y	0.548	0.000	Y	0.605	0.000	Y	0.734	0.000
The United Kingdom	N	-0.453	1.000	N	-0.330	0.998	N	-0.142	0.891
Australia	Y	0.500	0.000	Y	0.544	0.000	Y	0.855	0.000
Japan	N	-0.339	0.999	N	-0.338	0.999	N	-0.023	0.585
Belgium	Y	0.264	0.000	Y	0.256	0.001	Y	0.463	0.000
Korea	Y	0.399	0.000	Y	0.415	0.000	Y	0.455	0.000
Indonesia	N	-0.127	0.990	N	-0.044	0.697	Y	0.209	0.000
Malaysia	N	-0.211	0.997	N	-0.237	0.998	Y	0.129	0.047
Taiwan	Y	0.244	0.000	Y	0.257	0.000	Y	0.355	0.000
Philippines	Y	0.220	0.000	Y	0.207	0.000	Y	0.407	0.000
Argentina	Y	0.246	0.000	Y	0.238	0.001	Y	0.345	0.000
China	Y	0.341	0.001	Y	0.323	0.002	Y	0.367	0.000
India	Y	0.453	0.000	Y	0.447	0.000	Y	0.521	0.000
Brazil	N	-0.465	0.999	N	-0.391	0.996	N	-0.295	0.980
Chile	N	-0.031	0.613	N	-0.012	0.545	N	0.117	0.130
Mexico	N	-0.551	1.000	N	-0.475	0.999	N	-0.377	0.998
Iceland	N	0.010	0.438	N	0.018	0.395	N	-0.003	0.525
Turkey	N	0.128	0.071	N	0.126	0.078	Y	0.226	0.003

P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

However, the three countries that indicate significant changes in interdependence but no contagion - Italy, the United Kingdom, and Brazil - all have estimated contagion dates ending in the summer of 1997, before the crisis in Hong Kong even began. This can be seen in Table 10 which shows the contagion dates for the Hong Kong crisis. Each of these three countries also have positive θ_4 estimates, indicating that the interdependence structure increased around the time of the crisis in Hong Kong - which is precisely the definition of contagion. However, before concluding that these are in fact undiagnosed cases of contagion, it is important to note that the Bai and Perron (2003a) test determined that the most significant structural breaks occurred before the crisis itself. Still, this does present a weakness of this framework which should be taken into consideration.

Table 9: Test for significance of change in pre- and post- crisis interdependence, Hong Kong

Country	No Global Shock Contagion?	θ_4	P-value	Global shock Contagion?	θ_4	P-value
United States	N	-0.068	0.429	N	-0.066	0.435
Canada	Y	0.029	0.658	Y	0.017	0.796
Finland	Y	0.208	0.000	Y	0.200	0.001
France	Y	0.034	0.736	Y	0.091	0.172
Germany	Y	-0.106	0.404	Y	-0.081	0.544
Ireland	Y	0.034	0.567	Y	0.032	0.605
Italy	N	0.149	0.012	N	0.166	0.005
The Netherlands	Y	0.055	0.344	Y	0.066	0.260
Spain	Y	-0.064	0.559	Y	0.043	0.566
Slovakia	Y	0.020	0.817	Y	0.130	0.026
Switzerland	Y	0.151	0.008	Y	0.133	0.019
The United Kingdom	N	0.196	0.001	N	0.214	0.000
Australia	Y	0.111	0.042	Y	0.104	0.057
Japan	Y	0.089	0.182	N	0.005	0.945
Belgium	Y	-0.073	0.301	Y	-0.023	0.704
Korea	Y	0.141	0.147	Y	0.141	0.164
Indonesia	Y	0.006	0.933	N	0.103	0.200
Malaysia	N	-0.088	0.116	N	-0.046	0.412
Taiwan	Y	0.045	0.562	Y	0.048	0.541
Philippines	Y	-0.108	0.121	Y	-0.046	0.535
Argentina	Y	-0.091	0.370	Y	-0.076	0.469
China	Y	-0.295	0.015	Y	-0.294	0.018
India	Y	-0.031	0.659	Y	-0.020	0.776
Brazil	N	0.120	0.045	N	0.131	0.028
Chile	N	0.087	0.208	N	0.074	0.284
Mexico	Y	0.074	0.319	N	0.089	0.299
Iceland	N	0.011	0.886	N	0.025	0.740
Turkey	N	-0.007	0.908	N	-0.010	0.893

P-values are for the null hypothesis $H_0 : \theta_4 = 0$. The results of the corresponding contagion test are also included at the 95% significance level.

The optimal break dates for each country, shown in Table 10, indicate that contagion from Hong Kong occurred primarily in October 1997, coinciding with the collapse of the Hong Kong stock market. Of these cases, the most common date by far is October 22, 1997, which is the same as the starting date of the crisis in Hong Kong. Table 10 shows that contagion at this time was international in scope. Europe in particular seems the most vulnerable during this period with Finland, France, the Netherlands, Spain, Slovakia, Switzerland, and Belgium all having start dates around this time. The remaining cases are not as congregated around a particular date but most occur in the summer of 1998. Contrary to the 2007 crisis, here we see many contagion cases coinciding with the Hong Kong crisis. Of the 54 total cases of contagion between the two filters, 11 have break dates on October 22, 1997, the same day the crisis began in Hong Kong, and another six have starting dates within a week of the crisis.

While these 17 cases can be considered a lot compared to the 2007 crisis, which found only one country with a start date near the crisis, this still represents less than half of the 37 total cases of contagion found by the unrestricted test between the two filers. Importantly, these dates are not detected in traditional contagion tests, which most commonly either choose the dates arbitrarily or endogenously test for crisis dates rather than a break in the interdependence structure. This demonstrates the power of the models used in this paper which are flexible enough to detect both start and end dates endogenously over the sample period. This point is made even more clear when considering the end dates determined by the contagion tests. These show the contagious period lasting anywhere from a couple of months to almost two years. Again, this indicates that a one-size-fits-all approach to contagion testing is clearly not appropriate.

There are also several cases of contagion beginning or occurring entirely before the start of the crisis period. In the former category the dates mostly fall between June and early October of 1997, coinciding well with either the collapse of the Thai baht

Table 10: Contagion dates, Hong Kong

Country	No Global Shock Contagion?	Start date	End date	Global Shock Contagion?	Start date	End date
United States	N	Sep 11, 1995	Dec 4, 1995	N	Sep 11, 1995	Dec 5, 1995
Canada	Y	Oct 28, 1997	Aug 11, 1998	Y	Oct 28, 1997	Aug 11, 1998
Finland	Y	Oct 22, 1997	Jan 28, 1998	Y	Oct 22, 1997	Feb 6, 1998
France	Y	Jul 22, 1997	Aug 6, 1999	Y	Oct 22, 1997	Jun 9, 1998
Germany	Y	Mar 8, 1996	Sep 29, 1999	Y	Mar 7, 1996	Sep 29, 1999
Ireland	Y	Sep 15, 1997	Mar 12, 1998	Y	Sep 15, 1997	Mar 12, 1998
Italy	N	Mar 13, 1997	Jun 19, 1997	N	Mar 13, 1997	Jun 18, 1997
The Netherlands	Y	Oct 22, 1997	Jun 9, 1998	Y	Oct 22, 1997	Jun 9, 1998
Spain	Y	Oct 22, 1997	Aug 6, 1999	Y	Oct 8, 1997	Jan 26, 1999
Slovakia	Y	Oct 22, 1997	May 6, 1999	Y	Oct 22, 1997	Feb 6, 1998
Switzerland	Y	Oct 22, 1997	Feb 6, 1998	Y	Oct 22, 1997	Feb 6, 1998
The United Kingdom	N	Mar 21, 1997	Jul 3, 1997	N	Mar 21, 1997	Jul 3, 1997
Australia	Y	Oct 27, 1997	Mar 11, 1998	Y	Oct 27, 1997	Mar 11, 1998
Japan	Y	Jun 26, 1996	Mar 6, 1997	N	Aug 3, 1998	Oct 28, 1998
Belgium	Y	Oct 22, 1997	Dec 24, 1998	Y	Oct 28, 1997	Jul 14, 1998
Korea	Y	May 28, 1998	Jul 28, 1999	Y	May 28, 1998	Jul 28, 1999
Indonesia	Y	Dec 21, 1995	Mar 21, 1996	N	Aug 30, 1995	Aug 14, 1997
Malaysia	N	Feb 20, 1997	Sep 4, 1997	N	Feb 25, 1997	Sep 4, 1997
Taiwan	Y	Oct 27, 1997	Feb 5, 1999	Y	Oct 27, 1997	Feb 5, 1999
Philippines	Y	Jun 17, 1998	Jan 27, 1999	Y	Jun 18, 1997	Feb 23, 1999
Argentina	Y	Jul 20, 1998	Jul 15, 1999	Y	Jul 20, 1998	Jul 15, 1999
China	Y	May 13, 1999	Sep 15, 1999	Y	May 13, 1999	Sep 15, 1999
India	Y	May 25, 1998	Oct 8, 1998	Y	Apr 27, 1998	Oct 8, 1998
Brazil	N	Apr 30, 1997	Jul 31, 1997	N	Apr 30, 1997	Jul 31, 1997
Chile	N	Jul 17, 1998	Oct 19, 1998	N	Jul 20, 1998	Oct 19, 1998
Mexico	Y	Jun 18, 1997	Dec 7, 1998	N	Aug 22, 1995	Dec 19, 1995
Iceland	N	Jul 29, 1997	Nov 5, 1998	N	Jul 29, 1997	Nov 5, 1998
Turkey	N	Nov 7, 1996	Feb 19, 1997	N	Jul 6, 1998	Jan 13, 1999

The contagion dates are determined by the Bai and Perron (2003a) test using a 5% trim parameter. The results of the unrestricted contagion test, which allows the interdependence structures to change in the pre- and post-contagious periods, are also included at the 95% significance level.

or the crisis in Hong Kong, but commencing before the crisis in Hong Kong began. However, it is important to emphasize that the break dates themselves for both the crisis and the contagion are simply point estimates with standard errors. Hence, small discrepancies of a few weeks are not of great concern. The one stand out case is Germany, which has a stable starting date in March 1996, regardless of the filter. Japan and Indonesia fall into the latter category with terminal contagion dates of March 6, 1997 and March 21, 1996, respectively, without a global shock. While these are clearly well before the start of the crisis in Hong Kong, both countries lose significance when the global shock is included.

There are 17 countries testing positively for contagion under both filters: Canada, Finland, France, Germany, Ireland, the Netherlands, Spain, Slovakia, Switzerland, Australia, Belgium, Korea, Taiwan, the Philippines, Argentina, China, and India. Of these, 11 have break dates that are stable to the addition of the global shock, India has a small change of approximately one month, and the rest have dates fluctuating by several months or more. From this I consider the dates to be quite stable to the addition of the global shock.

Recall that our earlier estimation indicated crisis dates of October 22, 1997 until February 12, 1998, a period of 113 days. The average lengths of a contagious period, with and without a global shock, are 328 and 367 days. That the average contagion lengths are quite close supports the stability of the contagion dates, claimed above. The lengths themselves mirror the 2007 crisis, which returned average contagious periods greater than the crisis period. Indonesia has the shortest window, only 91 days, however it no longer tests positively for contagion when the global shock is added to the filter. The country with the smallest period of contagion testing positively under both filters is Finland, which has windows of 107 and 98 days long, with and without the shock. Germany has far and away the longest contagious periods under both filters, 1300 and 1301 days - more than 3 times the average contagious period and 11 times the actual crisis period itself. Focussing on the filter with the global shock, Korea, Taiwan, and the Philippines - the East Asian countries showing signs of contagion - all have contagious periods greater than average. Conversely, excepting Spain and Germany, the European and other developed economies have contagious periods less than the average. This is the opposite result obtained from the 2007 crisis and may suggest that the length of contagious periods not only tend to show regional effects, but also last longer in economies more similar to the source country.

We now consider tests for contagion originating from Thailand, beginning with Table 11, which shows the results without the inclusion of a global shock. To begin with, clearly there are far fewer cases of contagion originating from the Thai market compared to Hong Kong - the restricted and unrestricted tests each detect the same 11 cases of contagion, and the Morales and Andreosso-O'Callaghan (2014) test detects contagion for 12 countries. This is likely due to the size of the Thai economy, which is much smaller than that of Hong Kong, and supports earlier studies which generally consider the collapse of the Hong Kong stock market as the starting point of the crisis. However, even the 11 cases found in the first two tests represents over one-third of the sample, indicating that contagion from Thailand was not insignificant. Unlike Hong Kong, Europe and North America are almost completely insulated from contagion originating from Thailand. Only Ireland tests positively, and does so under all three tests. Rather, the crisis seemed to spread more to developing countries internationally, and a few larger economies regionally. Korea, Taiwan, and the large Japanese market were all affected locally, and Argentina, China, India, Brazil, Chile, Mexico, and Turkey test positively internationally.

Table 12 shows that the outcome of the contagion tests changes dramatically when the global shock is included. The restricted and unrestricted tests in particular fall from 11 to only six positive cases of contagion: Ireland, Taiwan, Argentina, India, Brazil, and Mexico. Notably, Taiwan is the only country in the East Asian region

Table 11: Contagion originating in Thailand, without a global shock

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
United States	N	-0.311	1.000	N	-0.271	0.999	N	-0.192	0.995
Canada	N	-0.380	1.000	N	-0.342	1.000	N	-0.162	0.998
Finland	N	-0.395	1.000	N	-0.440	1.000	N	-0.250	0.993
France	N	-0.404	1.000	N	-0.370	1.000	N	-0.221	0.989
Germany	N	-0.241	0.999	N	-0.146	0.951	N	-0.027	0.638
Ireland	Y	0.282	0.004	Y	0.310	0.002	Y	0.392	0.000
Italy	N	-0.115	0.864	N	-0.067	0.734	N	0.008	0.468
The Netherlands	N	-0.263	1.000	N	-0.218	0.997	N	-0.053	0.818
Spain	N	-0.280	1.000	N	-0.255	0.997	N	-0.101	0.897
Slovakia	N	0.138	0.135	N	0.152	0.116	Y	0.258	0.018
Switzerland	N	-0.234	0.997	N	-0.180	0.972	N	-0.038	0.681
The United Kingdom	N	-0.336	1.000	N	-0.326	1.000	N	-0.137	0.971
Australia	N	-0.306	1.000	N	-0.214	0.994	N	-0.028	0.656
Japan	Y	0.289	0.004	Y	0.293	0.005	Y	0.447	0.000
Belgium	N	-0.276	1.000	N	-0.233	0.997	N	-0.106	0.949
Korea	Y	0.499	0.000	Y	0.566	0.000	Y	0.597	0.000
Indonesia	N	-0.335	1.000	N	-0.355	1.000	N	0.000	0.501
Malaysia	N	-0.594	1.000	N	-0.564	1.000	N	-0.276	0.994
Taiwan	Y	0.224	0.000	Y	0.254	0.000	Y	0.317	0.000
Philippines	N	-0.360	1.000	N	-0.451	1.000	N	0.016	0.357
Argentina	Y	0.500	0.000	Y	0.551	0.000	Y	0.560	0.000
China	Y	0.287	0.021	Y	0.332	0.012	Y	0.328	0.009
India	Y	0.353	0.000	Y	0.297	0.000	Y	0.381	0.000
Brazil	Y	0.161	0.005	Y	0.187	0.002	Y	0.198	0.000
Chile	Y	0.422	0.000	Y	0.432	0.000	Y	0.488	0.000
Mexico	Y	0.267	0.000	Y	0.270	0.000	Y	0.316	0.000
Iceland	N	0.035	0.297	N	0.051	0.231	N	0.029	0.300
Turkey	Y	0.212	0.045	Y	0.209	0.049	Y	0.353	0.002

P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

Table 12: Contagion originating in Thailand, with a global shock

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
United States	N	-0.226	1.000	N	-0.272	0.996	N	-0.056	0.891
Canada	N	-0.338	1.000	N	-0.313	1.000	N	-0.123	0.987
Finland	N	-0.420	1.000	N	-0.455	0.999	N	-0.275	0.991
France	N	-0.412	1.000	N	-0.428	1.000	N	-0.202	0.981
Germany	N	-0.279	0.999	N	-0.198	0.979	N	-0.066	0.784
Ireland	Y	0.443	0.000	Y	0.467	0.000	Y	0.558	0.000
Italy	N	-0.041	0.656	N	0.005	0.482	N	0.077	0.220
The Netherlands	N	-0.349	1.000	N	-0.307	1.000	N	-0.152	0.976
Spain	N	-0.256	0.997	N	-0.245	0.992	N	-0.081	0.824
Slovakia	N	0.009	0.471	N	0.028	0.409	N	0.132	0.130
Switzerland	N	-0.295	0.999	N	-0.261	0.994	N	-0.100	0.866
The United Kingdom	N	-0.333	1.000	N	-0.337	1.000	N	-0.137	0.962
Australia	N	-0.425	1.000	N	-0.350	0.999	N	-0.151	0.937
Japan	N	-0.345	0.996	N	-0.425	0.998	N	-0.134	0.855
Belgium	N	-0.264	1.000	N	-0.244	0.996	N	-0.103	0.925
Korea	N	-0.632	1.000	N	-0.480	1.000	N	-0.436	1.000
Indonesia	N	-0.262	1.000	N	-0.270	1.000	Y	0.105	0.032
Malaysia	N	-0.261	1.000	N	-0.379	1.000	N	0.071	0.103
Taiwan	Y	0.367	0.000	Y	0.438	0.000	Y	0.479	0.000
Philippines	N	-0.340	1.000	N	-0.441	1.000	N	0.015	0.379
Argentina	Y	0.501	0.000	Y	0.557	0.000	Y	0.547	0.000
China	N	-0.311	0.959	N	-0.186	0.839	N	-0.246	0.919
India	Y	0.279	0.000	Y	0.207	0.005	Y	0.290	0.000
Brazil	Y	0.399	0.001	Y	0.436	0.000	Y	0.462	0.000
Chile	N	-0.247	0.985	N	-0.249	0.985	N	-0.117	0.857
Mexico	Y	0.414	0.000	Y	0.418	0.000	Y	0.469	0.000
Iceland	N	0.027	0.336	N	0.043	0.273	N	0.022	0.338
Turkey	N	0.103	0.125	N	0.100	0.138	Y	0.250	0.002

P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

affected by Thailand, yet Latin America contains half of the contagion cases. Like the Hong Kong crisis, the bias of the Morales and Andreosso-O'Callaghan (2014) test is not as clear when analyzing only the results of the contagion tests. While it still overestimates the cases of contagion, it only indicates two more cases here, and only one more when the global shock is not included. However, the size of the contagion coefficients are still almost always larger for this test when compared to the other two. As mentioned, this is a result of the failure of the Morales and Andreosso-O'Callaghan (2014) test to filter out any of the positive correlation between countries during tranquil times. Comparing the contagion coefficients themselves, they actually appear relatively stable between the two filters. Despite the change in significance, there are few cases of large jumps in the parameter estimates.

Evidence of change in the interdependence structure between the pre- and post-contagion periods for Thailand is roughly in line with the results for Hong Kong, showing six estimates significant at the conventional level. These results are contained in Table 13. Again, most cases tend to have positive coefficients indicating a stronger post-contagion relationship between the pair of countries. However, there is no clear link between significant contagion effects and the significance of $\hat{\theta}_4$. The only regional cases without the global shock are Korea and Australia. Including the additional variable in the filter however, Korea, Malaysia, Taiwan, and China represent four of the six significant cases. This is quite different than the results for Hong Kong, which showed stable relationships with all East Asian countries. Without the global shock the additional cases are primarily made up of other emerging markets, indicating that the stronger relationship between the set of countries is actually explained better by global economic conditions than an actual increase in the interdependence structure.

Table 13: Test for significance of change in pre- and post- crisis interdependence, Thailand

Country	No Global Shock Contagion?	θ_4	P-value	Global shock Contagion?	θ_4	P-value
United States	N	0.077	0.234	N	-0.056	0.576
Canada	N	0.064	0.359	N	0.038	0.602
Finland	N	-0.053	0.527	N	-0.040	0.651
France	N	0.054	0.397	N	-0.024	0.756
Germany	N	0.161	0.009	N	0.124	0.057
Ireland	Y	0.069	0.265	Y	0.052	0.409
Italy	N	0.119	0.051	N	0.102	0.099
The Netherlands	N	0.069	0.309	N	0.064	0.330
Spain	N	0.041	0.515	N	0.016	0.815
Slovakia	N	0.052	0.446	N	0.067	0.326
Switzerland	N	0.091	0.148	N	0.052	0.427
The United Kingdom	N	0.016	0.805	N	-0.006	0.926
Australia	N	0.145	0.023	N	0.103	0.123
Japan	Y	0.013	0.856	N	-0.098	0.242
Belgium	N	0.067	0.315	N	0.028	0.691
Korea	Y	0.234	0.000	N	0.213	0.001
Indonesia	N	-0.030	0.623	N	-0.011	0.880
Malaysia	N	0.056	0.307	N	-0.155	0.032
Taiwan	Y	0.116	0.163	Y	0.155	0.021
Philippines	N	-0.109	0.237	N	-0.117	0.229
Argentina	Y	0.178	0.008	Y	0.168	0.012
China	Y	0.076	0.223	N	0.156	0.041
India	Y	-0.169	0.020	Y	-0.169	0.022
Brazil	Y	0.246	0.037	Y	0.113	0.089
Chile	Y	0.033	0.621	N	-0.006	0.928
Mexico	Y	0.009	0.892	Y	0.010	0.872
Iceland	N	0.053	0.491	N	0.042	0.585
Turkey	Y	-0.012	0.861	N	-0.012	0.871

P-values are for the null hypothesis $H_0 : \theta_4 = 0$. The results of the corresponding contagion test are also included at the 95% significance level.

The contagion dates are shown in Table 14. Compared to the earlier crises in Hong Kong and the United States, there are far fewer cases of contagion occurring before the crisis period. Only China has a starting date before June 20, 1997, but the contagion coefficient loses its significance when the global shock is added to the filter. The remaining cases mostly land between September 1997 and January 1998, with the Latin American countries generally falling into the first half of 1998. Notably, none of the countries have contagion dates coinciding exactly with the start of the crisis in Thailand. The six countries testing positively for contagion under both filters are Ireland, Taiwan, Argentina, India, Brazil, and Mexico. Ireland and Argentina have dates that are relatively stable when the global shock is introduced to the model, with variations of only a few weeks for the former and no change at all for the latter. The remaining four cases have a discrepancy in either the start or end date of at

Table 14: Contagion dates, Thailand

Country	No Global Shock			Global Shock		
	Contagion?	Start date	End date	Contagion?	Start date	End date
United States	N	Mar 17, 1997	Dec 22, 1997	N	Aug 23, 1995	Jan 7, 1998
Canada	N	Sep 25, 1996	Jan 7, 1998	N	Sep 26, 1996	Jan 7, 1998
Finland	N	Nov 8, 1995	Apr 19, 1996	N	Nov 8, 1995	Apr 19, 1996
France	N	Nov 27, 1996	Jun 13, 1997	N	Oct 2, 1996	Jun 13, 1997
Germany	N	Dec 18, 1996	Aug 7, 1997	N	Dec 18, 1996	Aug 7, 1997
Ireland	Y	Nov 20, 1997	Mar 12, 1998	Y	Dec 3, 1997	Mar 9, 1998
Italy	N	Nov 10, 1997	Apr 6, 1998	N	Nov 12, 1997	Apr 6, 1998
The Netherlands	N	Jul 24, 1996	Aug 20, 1997	N	Nov 14, 1996	Aug 20, 1997
Spain	N	Nov 27, 1996	Jul 16, 1997	N	Nov 21, 1996	Jul 16, 1997
Slovakia	N	Jul 20, 1998	Oct 8, 1998	N	Jul 20, 1998	Oct 8, 1998
Switzerland	N	Nov 27, 1996	Jul 10, 1997	N	Nov 27, 1996	Jul 10, 1997
The United Kingdom	N	Oct 1, 1996	Jul 4, 1997	N	Oct 1, 1996	Jun 25, 1997
Australia	N	Sep 24, 1996	Jul 4, 1997	N	Sep 30, 1996	Feb 20, 1997
Japan	Y	May 29, 1998	Oct 7, 1998	N	Dec 28, 1995	Jul 1, 1996
Belgium	N	Aug 30, 1996	Jul 15, 1997	N	Aug 30, 1996	Jul 15, 1997
Korea	Y	Jun 9, 1998	Oct 1, 1998	N	Nov 13, 1996	Feb 13, 1997
Indonesia	N	Sep 3, 1996	Feb 17, 1997	N	Apr 18, 1996	Aug 4, 1997
Malaysia	N	May 19, 1997	Aug 18, 1997	N	Apr 1, 1996	Aug 12, 1997
Taiwan	Y	Sep 12, 1997	Feb 5, 1999	Y	Sep 25, 1997	Mar 9, 1998
Philippines	N	Jul 13, 1995	Aug 22, 1997	N	Jul 11, 1995	Aug 8, 1997
Argentina	Y	Mar 24, 1998	Aug 21, 1998	Y	Mar 24, 1998	Aug 21, 1998
China	Y	Jan 15, 1997	May 12, 1997	N	Mar 27, 1996	Jun 19, 1996
India	Y	Jan 7, 1998	Sep 30, 1998	Y	Aug 12, 1997	Sep 30, 1998
Brazil	Y	Jan 7, 1998	Aug 18, 1999	Y	May 14, 1998	Aug 11, 1998
Chile	Y	Jan 15, 1998	Aug 11, 1998	N	Jul 20, 1998	Oct 19, 1998
Mexico	Y	Jan 7, 1998	Sep 9, 1998	Y	May 14, 1998	Aug 11, 1998
Iceland	N	Jul 29, 1997	Nov 5, 1998	N	Jul 29, 1997	Nov 5, 1998
Turkey	Y	Jul 6, 1998	Oct 6, 1998	N	Jul 6, 1998	Jan 13, 1999

The contagion dates are determined by the Bai and Perron (2003a) test using a 5% trim parameter. The results of the unrestricted contagion test, which allows the interdependence structures to change in the pre- and post-contagious periods, are also included at the 95% significance level.

least several months. This is relatively large compared to Hong Kong and the United States, which had relatively fewer large variations in the contagion dates, and implies that the global shock variable is perhaps more important in the case of smaller markets to avoid any spurious correlations.

Recall that Thailand's estimated crisis dates were June 20, 1997 and March 12, 1999, a period of 630 days - much longer than either the Hong Kong or American crisis. By contrast, the average contagious period is only 167 days with the global shock and 230 without. This is the opposite of both earlier crises, where the contagious period was generally found to outlast the crisis itself. The shortest contagious periods among countries testing positively under both filters belong to Ireland, with lengths of 96 and 112 days, with and without the global shock. India has the longest periods of 414 days with the global shock and 266 without. In general the addition of the global shock tends to decrease the size of the contagious period - only India shows an increase under the modified filter, and completely dominates the sample as the only country with an above-average period. Latin American countries, which make up half of the positive contagion cases, also make up three of the four shortest periods, indicating that contagion to this region was generally short in duration.

5 Discussion

In this paper I reported and analyzed the results both with and without the global shock variable due to concerns that contagion could actually be transmitted through the shock itself, leading to the under-rejection of the null hypothesis. Since the results for the 2007 crisis show little change when the variable is added, and the U.S. interest rate would not likely be a transmitter of contagion in the East Asian region, this does not seem to have been an issue in this study.

The global shock variable does appear to have a much larger effect on the outcome of the contagion tests for a smaller source economy, however. When the variable is added to the 2007 crisis the results are quite consistent, with only a handful of minor changes. Conversely, the results for contagion during the Asian crisis originating from either Hong Kong or Thailand change dramatically when the variable is added to the model. This is intuitive since, as discussed, larger countries such as the United States make up a greater fraction of the global economy. Hence, they would be more correlated with any variable representing global economic conditions. Of course, this is especially true here because of the use of the short-term U.S. interest rate as the instrument.

Since Morales and Andreosso-O'Callaghan (2014) concern themselves exclusively with the 2007 crisis, using the United States as the source country, their omission of a variable to control for global economic conditions is not likely to severely affect their results. However, the results of the Asian crisis clearly show the danger of excluding this variable when considering crises originating in smaller countries. Including both Thailand and Hong Kong as source countries in the Asian crisis allows us to compare the effects of contagion from different sized markets while holding global conditions constant. The results indicate that smaller markets tend to pose more of a risk to regional or developing markets. Developed markets further from the source country seem to be much less likely to contract any contagion from a smaller market.

An important difference between the 2007 and 1997 crises is the change in the international financial sector over the decade between these two crises. Indeed, the results obtained in Section 4 suggest that market integration plays an important role in how each of the three tests measures contagion. Clearly the bias of the Morales and Andreosso-O'Callaghan (2014) test, which fails to allow for market correlation in tranquil periods, will be greater for more integrated financial markets. However, we also notice that, while the results of the restricted and unrestricted tests differ for the 2007 crisis, they produce virtually identical results for both Hong Kong and Thailand during the Asian crisis. Notice that the restricted test is simply a special case of the unrestricted test, where θ_4 is forced to equal zero, so that correlation in the pre- and post-contagious periods must be the same. If integration is low in normal times then the differences between these two tests should be minimal, whereas a greater degree of integration would lead to more of a difference.

Finally, the results indicate that larger, more integrated markets are, on average, more likely to be the source of much longer stints of contagion. When the global shock variable is included in the filter, the United States had the longest average period of contagion, 652 days, followed by Hong Kong with 328 days, and finally Thailand with only 167 days. This is despite the fact that Thailand features the longest crisis period, defined as a prolonged episode of higher-than-usual volatility, more than a year longer than the next longest crisis in the United States.

To demonstrate the change in market integration between the two periods, and hence the greater differences between the three tests, I run the following simple regressions over the pre-crisis periods for the Asian and American crises:

$$\mu_{i,t} = \varphi + \theta\mu_{c,t} + \eta_t \tag{13}$$

where, as before, $\mu_{i,t}$ and $\mu_{c,t}$ are the standardized residuals of country i and the contagious country, respectively. We take the United States, Thailand, and Hong Kong as the contagious countries to see if there is a change in the pre-crisis interdependence structures between the two periods. The results, shown in Table 15, overwhelmingly support the idea that interdependence increased between the two sample periods. Virtually every country shows an increase in $\hat{\theta}$, with only Malaysia and the United States becoming less correlated. This is especially true for the smaller Thai and Hong Kong markets: while the United States shows an average increase in $\hat{\theta}$ of 201%, Hong Kong and Thailand have average increases of 306% and 375%, respectively. The table also illustrates that Hong Kong and Thailand have relatively low 1997 pre-crisis

Table 15: Difference in pre-crisis interdependence, 1997 vs 2007

	United States			Hong Kong			Thailand		
	1997	2007	% change	1997	2007	% change	1997	2007	% change
Canada	0.450	0.643	42.73	0.130	0.168	29.45	0.061	0.120	97.15
Finland	0.292	0.421	44.24	0.138	0.345	150.24	0.029	0.226	670.49
France	0.307	0.709	131.40	0.166	0.408	145.33	0.091	0.299	228.78
Germany	0.197	0.499	153.86	0.266	0.336	26.45	0.085	0.231	171.57
Ireland	0.188	0.441	134.83	0.233	0.365	56.33	0.094	0.227	141.66
Italy	0.155	0.415	167.09	0.068	0.278	308.26	0.055	0.221	304.75
The Netherlands	0.267	0.521	94.92	0.211	0.347	64.40	0.058	0.223	286.41
Spain	0.261	0.455	74.30	0.087	0.305	250.02	0.079	0.250	215.40
Slovakia	0.324	0.466	43.82	0.160	0.368	129.05	0.056	0.261	366.97
Switzerland	0.201	0.433	114.93	0.117	0.334	186.24	0.090	0.207	129.76
The United Kingdom	0.299	0.468	56.91	0.154	0.348	125.86	0.090	0.259	187.73
Australia	0.125	0.133	5.80	0.334	0.629	88.25	0.112	0.370	229.57
Japan	0.054	0.145	167.28	0.265	0.584	120.73	0.165	0.289	75.59
Belgium	0.206	0.482	134.13	0.191	0.334	74.80	0.038	0.237	526.87
Korea	0.085	0.185	117.27	0.023	0.523	2159.61	0.014	0.289	1899.93
Indonesia	0.130	0.125	-3.90	0.234	0.470	101.10	0.232	0.299	28.77
Malaysia	0.011	0.108	869.52	0.322	0.360	11.85	0.271	0.276	1.73
Taiwan	0.037	0.108	189.13	0.125	0.492	292.72	0.049	0.309	527.46
Philippines	0.050	0.090	82.06	0.204	0.316	54.85	0.146	0.238	62.46
Argentina	0.247	0.488	97.90	0.083	0.216	159.90	-0.031	0.147	574.18
China	-0.047	-0.011	77.11	0.041	0.285	596.74	0.038	0.077	103.29
India	-0.032	0.124	487.07	0.050	0.492	876.55	0.086	0.273	217.67
Brazil	0.224	0.583	160.83	0.073	0.178	145.28	0.008	0.131	1581.93
Chile	0.143	0.449	215.16	0.051	0.168	229.28	0.058	0.116	99.14
Mexico	0.217	0.589	171.79	0.044	0.182	310.17	0.056	0.134	140.58
Iceland	0.101	0.232	130.51	-0.023	0.287	1326.58	-0.029	0.302	1134.69
Turkey	0.012	0.198	1488.25	0.087	0.312	259.11	0.113	0.252	124.06

The 1997 pre-crisis period is defined to match the start date for the earlier crisis in Thailand so runs from January 1, 1995 - June 19, 1997. The 2007 pre-crisis period runs from January 1, 2005 - September 11, 2008.

interdependence structures.

This shows the importance of future contagion studies employing methods similar to the unrestricted test proposed in this paper, which make as few assumptions as possible about the stability of market structures and timing of contagion relative to crises. If the Asian crisis had occurred a decade later, it is almost certain that the bias in the restricted and Morales and Andreosso-O'Callaghan (2014) tests would be greater.

To further demonstrate the difference between the tests proposed in this paper, which endogenously estimate the contagion dates, and other tests based on using crisis dates to test for contagion, I re-run all three tests using the fixed crisis dates found in Section 4. For brevity, the results are included in Appendix C, rather than reported here. I use the standardized residuals from the filter including the global shock, considering these to be the most robust. Not surprisingly, the results change drastically, especially for contagion originating from Thailand and the United States. In particular, the bias of the Morales and Andreosso-O'Callaghan (2014) test is not nearly as subtle for the Asian crisis as was seen in Section 4.2. Most surprising, however, is the near absence of negative estimated contagion coefficients. This is quite different from our earlier results where negative coefficients were commonplace.

Indeed, if the contagion test proposed in Section 3 is modified to a two-sided hypothesis, so that the contagion coefficient is no longer restricted to be a positive number, many significant estimates emerge. I report the results of the unrestricted contagion test with this modification and the global shock filter in Tables 21, 22, and 23, found in Appendix C, for the United States, Hong Kong, and Thailand, respectively. The results for the United States and Thailand show many significant negative contagion coefficients occurring entirely before the start of the respective crises. In particular, Korea, Indonesia, Malaysia, and the Philippines all have significant negative estimates of θ_3 with Thailand as the contagious country, and the latter three have end dates near the beginning of the Thai crisis. Recall that the Bai and Perron (2003a) test simply returns the optimal partitions from a sample of data to minimize the sum of squared residuals. What these results imply, then, is that there are many cases where the optimal break is not a period of contagion, but rather one of decreased correlation during the run-up to a crisis. This yields an important result about contagion and how crises spread: correlations may not be constant over the crisis period. Rather, correlations often seem to first decrease late into the pre-crisis period before increasing later into the turmoil period.

This builds on the observation of Baek and Jun (2011), who suggest that contagion may not occur coincident with the start of a crisis, but rather takes some time to spread. The research in this paper takes this a step further by suggesting that contagion may often be preceded by a period of decreased correlation before the crisis starts, which we find to be more significant than later increases in correlation displayed by positive estimates of θ_4. Traditional contagion tests based on fixed crisis dates fail to observe this period of lessened correlation because the contagious and crisis periods are forced to coincide. The failure to account for this period of decreased correlation results in these tests over-estimating the presence of contagion. Since the crisis dates are fixed, the tranquil period is forced to include both the normal interdependence structure as well as this period of lessened correlation. Hence, tranquil period estimates, $\hat{\theta}_2$, are likely biased downwards because of the period of lower, and unaccounted for, correlation. A result of this is that even small increases in the interdependence structure appear artificially large, not because of an increase in correlation, but due to the biased tranquil period estimation.

6 Conclusion

The main result derived in this paper has been the discrepancy between the contagion and crisis dates. By incorporating the Bai and Perron (2003a) test to determine the structural breaks, I find that in the vast majority of cases the crisis and contagion dates do not coincide. This overturns a fundamental assumption of most contagion studies: that contagion lasts exactly as long as the crisis itself. Furthermore, the contagion dates themselves vary greatly between countries, in both timing and length. Accounting for this is especially important to achieve unbiased estimates of the contagion coefficients. By showing that there is generally a lead or lag between the crisis and the contagion, and the contagious period is not generally the same for all countries, this paper demonstrates how tests that fail to account for this are based on incorrect samples and hence produce biased estimates.

The results of this research suggest that the changes in cross-market correlations are more complicated than traditional contagion tests have assumed. Not only do the start and end dates of contagious episodes seem to vary greatly for different countries, the contagion coefficient itself is often unstable over the crisis period. This was shown by the abundance of highly significant but negative contagion coefficients dominating the Bai and Perron (2003a) test. Other studies that ignore this pre-crisis break rely on incorrect interdependence estimates, biased downwards by failing to account for this period of decreased correlation, and hence overestimate the presence of contagion. This offers an important contribution into the understanding of financial markets, specifically how stock markets behave around crisis episodes. Future work should look to test for additional structural breaks in order to properly measure each period of differing correlation.

This paper has also demonstrated the bias present in the recently proposed Morales and Andreosso-O'Callaghan (2014) test, which fails to account for normal interdependence structures, hence overestimating the presence of contagion. This is especially true for markets that are more integrated in the global economy for which the bias was seen to be much greater. In general, the results of this paper do not offer strong evidence of contagion as an omnipresent phenomenon. However, there is significant evidence that contagion is international in scope, and not simply a regional issue. Hence, an MGARCH specification, such as that proposed in Dungey et al. (2010), which is restricted to observing a smaller number of countries for practical purposes, may not be appropriate.

While many cases of contagion are found during both the 2007 and Asian financial crises, I find many significant negative coefficients when the hypothesis test developed in Section 3 is relaxed to allow for any break, rather than only an increase, in the interdependence structure. When this is taken into account, I show that most country pairs do undergo some type of break in the interdependence structure around a crisis, but it is not unilaterally positive, as most contagion research has assumed. This is significant because a smaller degree of correlation during crises would actually increase the diversification of portfolios, rather than decrease as suggested by Billio and Pelizzon (2003). I also show that post-contagion interdependence is often higher than in the pre-crisis period, suggesting that markets usually become more correlated after a crisis.

A List of countries and respective stock indices

Table 16: Countries and indices

Country	Index
Hong Kong	Hong Kong Seng Index
Korea	Korea Stock Exchange KOSPI Index
Indonesia	Jakarta Stock Exchange Composite Index
Malaysia	FTSE Bursa Malaysia KLCI Index - Kuala Lumpur Composite Index
Singapore	FTSE ST All-Share Index
Thailand	Stock Exchange of Thailand SET Index
Taiwan	Taiwan Stock Exchange Weighted Index
Philippines	Philippines Stock Exchange PSEI Index
Argentina	Buenos Aires Stock Exchange Merval Index
China	Shanghai Stock Exchange Composite Index
India	S&P BSE SENSEX Index
Russia	MICEX Index
South Africa	FTSE/JSE Africa All Share Index
Brazil	Ibovespa Brasil Sao Paulo Stock Exchange Index
Chile	Santiago Stock Exchange IPSA Index
Mexico	Mexican Stock Exchange Mexican Bolsa
Iceland	Iceland Stock Exchange ICEX Main Index
Turkey	Borsa Istanbul 100 Index
United States	NASDAQ Composite Index
Canada	S&P/TSX Composite Index
Finland	OMX Helsinki Index
France	CAC 40 Index
Germany	Deutsche Boerse AG German Stock Index DAX
Ireland	Irish Stock Exchange Overall Index
Italy	FTSE MIB
Netherlands	AEX Index
Spain	Madrid Stock Exchange General Index
Denmark	OMX Copenhagen Index
Norway	Oslo Stock Exchange Benchmark Index
Slovakia	Bratislava Stock Exchange
Switzerland	Swiss Market Index
United Kingdom	FTSE 100 Index
Australia	Australian Stock Exchange All Ordinaries Index
Japan	Nikkei 225
New Zealand	New Zealand Exchange 50 Gross Index
Belgium	Bel 20 Index

B Diagnostic tests

Table 17: P-values of ARCH-LM tests for 1997 and 2007 sample periods

	2007		1997	
	No global shock	Global Shock	No global shock	Global Shock
United States	0.013	0.024	0.011	0.013
Canada	0.064	0.028	0.369	0.302
Finland	0.727	0.804	0.050	0.026
France	0.713	0.126	0.185	0.473
Germany	0.869	0.282	0.180	0.179
Ireland	0.164	0.050	0.426	0.387
Italy	0.995	0.518	0.354	0.455
The Netherlands	0.799	0.343	0.028	0.005
Spain	0.598	0.166	0.194	0.167
Denmark	0.276	0.096		
Norway	0.455	0.176		
Slovakia	0.984	0.224	0.070	0.123
Switzerland	0.258	0.070	0.052	0.043
The United Kingdom	0.536	0.161	0.121	0.062
Australia	0.444	0.024	0.073	0.100
Japan	0.846	0.403	0.304	0.237
New Zealand	0.399	0.104		
Belgium	0.372	0.988	0.881	0.831
Hong Kong	0.498	0.253	0.245	0.631
Korea	0.707	0.163	0.105	0.613
Indonesia	0.380	0.623	0.001	0.998
Malaysia	0.116	0.578	0.504	0.866
Singapore	0.049	0.040		
Thailand	0.970	0.950	0.376	0.810
Taiwan	0.165	0.100	0.148	0.122
Philippines	0.368	0.543	0.127	0.868
Argentina	0.145	0.173	0.976	0.668
China	0.288	0.171	0.952	0.878
India	0.289	0.128	0.373	0.364
Russia	0.339	0.204		
South Africa	0.594	0.363		
Brazil	0.022	0.012	0.460	0.520
Chile	0.187	0.049	0.727	0.655
Mexico	0.674	0.262	0.485	0.248
Iceland	0.901	0.942	0.945	0.960
Turkey	0.451	0.360	0.756	0.812

C Modified contagion tests

Table 18: Contagion originating from the United States, using fixed crisis dates

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
Canada	Y	0.227	0.000	Y	0.227	0.000	Y	0.897	0.000
Finland	N	0.063	0.170	N	0.063	0.169	Y	0.589	0.000
France	N	0.028	0.322	N	0.028	0.322	Y	0.663	0.000
Germany	N	0.076	0.105	N	0.076	0.105	Y	0.715	0.000
Ireland	N	0.063	0.170	N	0.063	0.169	Y	0.589	0.000
Italy	N	0.028	0.322	N	0.028	0.322	Y	0.663	0.000
The Netherlands	N	0.076	0.105	N	0.076	0.105	Y	0.715	0.000
Spain	N	0.049	0.233	N	0.049	0.232	Y	0.555	0.000
Denmark	Y	0.136	0.025	Y	0.133	0.027	Y	0.655	0.000
Norway	N	0.039	0.262	N	0.039	0.262	Y	0.660	0.000
Slovakia	N	0.031	0.314	N	0.031	0.314	Y	0.603	0.000
Switzerland	Y	0.131	0.031	Y	0.130	0.031	Y	0.597	0.000
The United Kingdom	N	0.111	0.054	N	0.111	0.054	Y	0.572	0.000
Australia	N	0.059	0.182	N	0.059	0.182	Y	0.612	0.000
Japan	N	0.002	0.488	N	0.002	0.489	Y	0.566	0.000
New Zealand	N	0.057	0.178	N	0.057	0.178	Y	0.648	0.000
Belgium	N	-0.018	0.595	N	-0.017	0.594	Y	0.253	0.000
Hong Kong	N	0.046	0.287	N	0.046	0.287	Y	0.291	0.000
Korea	N	-0.086	0.867	N	-0.086	0.867	N	0.062	0.199
Indonesia	N	0.015	0.403	N	0.015	0.403	Y	0.588	0.000
Malaysia	N	0.090	0.111	N	0.090	0.111	Y	0.345	0.000
Singapore	N	0.079	0.141	N	0.079	0.141	Y	0.333	0.000
Thailand	N	-0.049	0.745	N	-0.048	0.745	Y	0.145	0.018
Taiwan	N	0.094	0.106	N	0.094	0.106	Y	0.284	0.000
Philippines	N	0.052	0.248	N	0.052	0.247	Y	0.342	0.000
Argentina	Y	0.181	0.007	Y	0.181	0.007	Y	0.343	0.000
China	N	0.103	0.107	N	0.103	0.107	Y	0.334	0.000
India	N	0.016	0.417	N	0.016	0.416	Y	0.157	0.013
Russia	Y	0.235	0.000	Y	0.235	0.000	Y	0.835	0.000
South Africa	N	0.100	0.116	N	0.099	0.117	Y	0.181	0.010
Brazil	Y	0.291	0.000	Y	0.291	0.000	Y	0.500	0.000
Chile	N	0.136	0.052	N	0.136	0.052	Y	0.482	0.000
Mexico	N	0.095	0.093	N	0.095	0.093	Y	0.493	0.000
Iceland	Y	0.236	0.000	Y	0.236	0.000	Y	0.897	0.000
Turkey	Y	0.204	0.001	Y	0.204	0.001	Y	0.735	0.000

The crisis period is defined as September 12, 2008 to May 26, 2009. P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

Table 19: Contagion originating from Hong Kong, using fixed crisis dates

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
United States	N	0.111	0.174	N	0.111	0.174	Y	0.234	0.021
Canada	Y	0.222	0.025	Y	0.222	0.024	Y	0.394	0.000
Finland	Y	0.468	0.000	Y	0.468	0.000	Y	0.710	0.000
France	Y	0.393	0.001	Y	0.393	0.001	Y	0.631	0.000
Germany	Y	0.445	0.000	Y	0.445	0.000	Y	0.740	0.000
Ireland	Y	0.316	0.006	Y	0.316	0.006	Y	0.584	0.000
Italy	Y	0.264	0.016	Y	0.264	0.016	Y	0.438	0.000
The Netherlands	Y	0.448	0.000	Y	0.449	0.000	Y	0.718	0.000
Spain	Y	0.263	0.015	Y	0.263	0.015	Y	0.433	0.000
Slovakia	Y	0.467	0.000	Y	0.467	0.000	Y	0.688	0.000
Switzerland	Y	0.509	0.000	Y	0.510	0.000	Y	0.697	0.000
The United Kingdom	Y	0.387	0.000	Y	0.387	0.000	Y	0.645	0.000
Australia	Y	0.417	0.000	Y	0.418	0.000	Y	0.783	0.000
Japan	Y	0.223	0.028	Y	0.223	0.028	Y	0.498	0.000
Belgium	Y	0.348	0.001	Y	0.348	0.001	Y	0.557	0.000
Korea	N	-0.290	0.996	N	-0.291	0.996	N	-0.115	0.855
Indonesia	Y	0.412	0.000	Y	0.413	0.000	Y	0.674	0.000
Malaysia	Y	0.228	0.014	Y	0.228	0.014	Y	0.525	0.000
Taiwan	Y	0.261	0.014	Y	0.262	0.014	Y	0.428	0.000
Philippines	Y	0.358	0.000	Y	0.359	0.000	Y	0.607	0.000
Argentina	N	0.107	0.188	N	0.107	0.186	Y	0.252	0.016
China	N	-0.101	0.803	N	-0.100	0.802	N	-0.046	0.657
India	Y	0.225	0.038	Y	0.226	0.037	Y	0.324	0.004
Brazil	Y	0.288	0.005	Y	0.289	0.005	Y	0.418	0.000
Chile	N	0.140	0.120	N	0.140	0.120	Y	0.278	0.009
Mexico	N	0.145	0.111	N	0.146	0.110	Y	0.282	0.008
Iceland	N	-0.028	0.595	N	-0.028	0.593	N	-0.031	0.606
Turkey	N	0.126	0.149	N	0.127	0.148	Y	0.234	0.024

The crisis period is defined as October 22, 1997 to February 12, 1998. P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

Table 20: Contagion originating from Thailand, using fixed crisis dates

Country	Restricted Contagion?	θ_3	P-value	Unrestricted Contagion?	θ_3	P-value	Morales et al Contagion?	ψ_2	P-value
United States	N	0.018	0.381	N	0.019	0.378	Y	0.084	0.035
Canada	N	0.057	0.170	N	0.058	0.167	Y	0.146	0.001
Finland	Y	0.143	0.009	Y	0.143	0.009	Y	0.197	0.000
France	N	0.027	0.345	N	0.028	0.340	Y	0.172	0.000
Germany	N	0.096	0.052	N	0.097	0.051	Y	0.225	0.000
Ireland	Y	0.165	0.004	Y	0.165	0.004	Y	0.242	0.000
Italy	N	0.051	0.194	N	0.051	0.197	Y	0.143	0.001
The Netherlands	N	0.083	0.080	N	0.082	0.081	Y	0.186	0.000
Spain	N	0.077	0.099	N	0.076	0.103	Y	0.181	0.000
Slovakia	N	0.055	0.184	N	0.056	0.178	Y	0.155	0.000
Switzerland	N	0.065	0.135	N	0.061	0.148	Y	0.193	0.000
The United Kingdom	N	0.045	0.224	N	0.044	0.228	Y	0.172	0.000
Australia	Y	0.163	0.003	Y	0.161	0.003	Y	0.328	0.000
Japan	N	0.040	0.260	N	0.042	0.251	Y	0.211	0.000
Belgium	N	0.079	0.092	N	0.078	0.097	Y	0.154	0.000
Korea	Y	0.160	0.002	Y	0.161	0.002	Y	0.253	0.000
Indonesia	Y	0.164	0.001	Y	0.163	0.001	Y	0.393	0.000
Malaysia	N	0.009	0.437	N	0.009	0.436	Y	0.271	0.000
Taiwan	N	0.074	0.129	N	0.075	0.125	Y	0.187	0.000
Philippines	Y	0.153	0.003	Y	0.151	0.003	Y	0.322	0.000
Argentina	Y	0.123	0.024	Y	0.122	0.024	Y	0.150	0.001
China	N	0.007	0.457	N	0.007	0.456	N	0.060	0.099
India	N	0.072	0.131	N	0.072	0.132	Y	0.119	0.007
Brazil	N	0.048	0.217	N	0.047	0.218	Y	0.115	0.006
Chile	N	0.005	0.465	N	0.006	0.462	Y	0.114	0.006
Mexico	N	0.059	0.163	N	0.058	0.170	Y	0.118	0.005
Iceland	N	-0.001	0.506	N	-0.001	0.504	N	0.005	0.461
Turkey	N	0.082	0.093	N	0.083	0.092	Y	0.207	0.000

The crisis period is defined as June 20, 1997 to March 12, 1998. P-values are for the null hypothesis $H_0 : \theta_3 \leq 0$. The results of the contagion test are summarized at the 95% significance level. Test 1 denotes the restricted, test 2 the unrestricted, and test 3 the Morales and Andreosso-O'Callaghan (2014) contagion test.

Table 21: Two-sided unrestricted contagion tests with global shock filter, United States

Country	θ_3	P-value	θ_4	P-value	Start date	End date
Canada	-0.393	0.000	0.143	0.000	Apr 17, 2008	Aug 26, 2008
Finland	-0.089	0.241	0.116	0.019	Sep 27, 2007	Jul 16, 2008
France	0.105	0.098	0.289	0.000	Mar 23, 2006	Mar 27, 2009
Germany	-0.124	0.037	0.142	0.004	Apr 26, 2007	Sep 18, 2008
Ireland	0.173	0.005	0.295	0.000	Feb 12, 2007	Mar 24, 2009
Italy	-0.271	0.026	0.080	0.178	Apr 26, 2007	Aug 6, 2007
The Netherlands	0.100	0.138	0.227	0.000	Mar 24, 2006	Jul 16, 2008
Spain	0.296	0.000	0.104	0.031	Mar 27, 2009	Dec 8, 2009
Denmark	-0.256	0.053	0.127	0.247	Jul 11, 2005	May 10, 2006
Norway	-0.230	0.033	0.324	0.000	Apr 16, 2008	Aug 20, 2008
Slovakia	0.076	0.265	0.198	0.000	Jun 1, 2007	Jul 16, 2008
Switzerland	0.207	0.003	0.320	0.000	Apr 10, 2006	Feb 26, 2009
The United Kingdom	0.103	0.060	0.268	0.000	Jun 29, 2007	Mar 26, 2009
Australia	0.190	0.006	0.315	0.000	Oct 16, 2006	Feb 5, 2009
Japan	-0.068	0.469	0.095	0.270	Jan 30, 2006	Feb 5, 2008
New Zealand	0.391	0.000	0.149	0.008	Dec 7, 2007	Jul 17, 2008
Belgium	0.244	0.000	0.374	0.000	Mar 22, 2006	Mar 20, 2009
Hong Kong	-0.141	0.189	0.138	0.008	Apr 29, 2008	Sep 18, 2008
Korea	-0.248	0.029	-0.024	0.810	Sep 1, 2005	Dec 11, 2006
Indonesia	0.135	0.047	0.217	0.001	Dec 6, 2006	Feb 3, 2009
Malaysia	0.788	0.000	0.247	0.000	Dec 6, 2006	Apr 24, 2007
Singapore	0.187	0.006	0.266	0.000	Jan 24, 2007	Mar 10, 2009
Thailand	0.295	0.000	0.108	0.047	Aug 15, 2008	Apr 6, 2009
Taiwan	0.139	0.186	0.166	0.003	May 19, 2008	Oct 28, 2008
Philippines	0.461	0.000	0.186	0.002	Feb 13, 2007	Aug 16, 2007
Argentina	-0.287	0.000	0.193	0.000	Dec 20, 2007	Aug 29, 2008
China	-0.309	0.001	0.110	0.062	Jan 18, 2008	Sep 12, 2008
India	0.309	0.000	0.078	0.211	Sep 12, 2008	Nov 23, 2009
Russia	0.305	0.002	0.566	0.000	Oct 4, 2005	Aug 14, 2008
South Africa	0.110	0.178	0.351	0.000	Feb 2, 2006	Jul 16, 2008
Brazil	0.208	0.000	-0.042	0.363	Sep 8, 2008	Nov 18, 2009
Chile	-0.381	0.001	0.072	0.264	Aug 16, 2010	Jan 27, 2011
Mexico	0.355	0.000	0.162	0.007	May 11, 2006	Oct 27, 2009
Iceland	0.249	0.002	0.027	0.676	Jul 2, 2007	Sep 29, 2008
Turkey	-0.529	0.000	-0.187	0.167	May 6, 2005	Feb 13, 2007

Table 22: Two-sided unrestricted contagion tests with global shock filter, Hong Kong

Country	θ_3	P-value	θ_4	P-value	Start date	End date
United States	-0.644	0.000	-0.066	0.435	Sep 11, 1995	Dec 5, 1995
Canada	0.270	0.001	0.017	0.796	Oct 28, 1997	Aug 11, 1998
Finland	0.592	0.000	0.200	0.001	Oct 22, 1997	Feb 6, 1998
France	0.392	0.000	0.091	0.172	Oct 22, 1997	Jun 9, 1998
Germany	0.257	0.000	-0.081	0.544	Mar 7, 1996	Sep 29, 1999
Ireland	0.261	0.008	0.032	0.605	Sep 15, 1997	Mar 12, 1998
Italy	-0.366	0.004	0.166	0.005	Mar 13, 1997	Jun 18, 1997
The Netherlands	0.422	0.000	0.066	0.260	Oct 22, 1997	Jun 9, 1998
Spain	0.274	0.000	0.043	0.566	Oct 8, 1997	Jan 26, 1999
Slovakia	0.545	0.000	0.130	0.026	Oct 22, 1997	Feb 6, 1998
Switzerland	0.605	0.000	0.133	0.019	Oct 22, 1997	Feb 6, 1998
The United Kingdom	-0.330	0.005	0.214	0.000	Mar 21, 1997	Jul 3, 1997
Australia	0.544	0.000	0.104	0.057	Oct 27, 1997	Mar 11, 1998
Japan	-0.338	0.002	0.005	0.945	Aug 3, 1998	Oct 28, 1998
Belgium	0.256	0.002	-0.023	0.704	Oct 28, 1997	Jul 14, 1998
Korea	0.415	0.000	0.141	0.164	May 28, 1998	Jul 28, 1999
Indonesia	-0.044	0.606	0.103	0.200	Aug 30, 1995	Aug 14, 1997
Malaysia	-0.237	0.005	-0.046	0.412	Feb 25, 1997	Sep 4, 1997
Taiwan	0.257	0.000	0.048	0.541	Oct 27, 1997	Feb 5, 1999
Philippines	0.207	0.000	-0.046	0.535	Jun 18, 1997	Feb 23, 1999
Argentina	0.238	0.001	-0.076	0.469	Jul 20, 1998	Jul 15, 1999
China	0.323	0.004	-0.294	0.018	May 13, 1999	Sep 15, 1999
India	0.447	0.000	-0.020	0.776	Apr 27, 1998	Oct 8, 1998
Brazil	-0.391	0.008	0.131	0.028	Apr 30, 1997	Jul 31, 1997
Chile	-0.012	0.909	0.074	0.284	Jul 20, 1998	Oct 19, 1998
Mexico	-0.475	0.002	0.089	0.299	Aug 22, 1995	Dec 19, 1995
Iceland	0.018	0.791	0.025	0.740	Jul 29, 1997	Nov 5, 1998
Turkey	0.126	0.156	-0.010	0.893	Jul 6, 1998	Jan 13, 1999

Table 23: Two-sided unrestricted contagion tests with global shock filter, Thailand

Country	θ_3	P-value	θ_4	P-value	Start date	End date
United States	-0.272	0.007	-0.056	0.576	Aug 23, 1995	Jan 7, 1998
Canada	-0.313	0.000	0.038	0.602	Sep 26, 1996	Jan 7, 1998
Finland	-0.455	0.001	-0.040	0.651	Nov 8, 1995	Apr 19, 1996
France	-0.428	0.000	-0.024	0.756	Oct 2, 1996	Jun 13, 1997
Germany	-0.198	0.042	0.124	0.057	Dec 18, 1996	Aug 7, 1997
Ireland	0.467	0.000	0.052	0.409	Dec 3, 1997	Mar 9, 1998
Italy	0.005	0.964	0.102	0.099	Nov 12, 1997	Apr 6, 1998
The Netherlands	-0.307	0.001	0.064	0.330	Nov 14, 1996	Aug 20, 1997
Spain	-0.245	0.015	0.016	0.815	Nov 21, 1996	Jul 16, 1997
Slovakia	0.028	0.818	0.067	0.326	Jul 20, 1998	Oct 8, 1998
Switzerland	-0.261	0.012	0.052	0.427	Nov 27, 1996	Jul 10, 1997
The United Kingdom	-0.337	0.000	-0.006	0.926	Oct 1, 1996	Jun 25, 1997
Australia	-0.350	0.002	0.103	0.123	Sep 30, 1996	Feb 20, 1997
Japan	-0.425	0.004	-0.098	0.242	Dec 28, 1995	Jul 1, 1996
Belgium	-0.244	0.008	0.028	0.691	Aug 30, 1996	Jul 15, 1997
Korea	-0.480	0.000	0.213	0.001	Nov 13, 1996	Feb 13, 1997
Indonesia	-0.270	0.001	-0.011	0.880	Apr 18, 1996	Aug 4, 1997
Malaysia	-0.379	0.000	-0.155	0.032	Apr 1, 1996	Aug 12, 1997
Taiwan	0.438	0.000	0.155	0.021	Sep 25, 1997	Mar 9, 1998
Philippines	-0.441	0.000	-0.117	0.229	Jul 11, 1995	Aug 8, 1997
Argentina	0.557	0.000	0.168	0.012	Mar 24, 1998	Aug 21, 1998
China	-0.186	0.322	0.156	0.041	Mar 27, 1996	Jun 19, 1996
India	0.207	0.011	-0.169	0.022	Aug 12, 1997	Sep 30, 1998
Brazil	0.436	0.000	0.113	0.089	May 14, 1998	Aug 11, 1998
Chile	-0.249	0.030	-0.006	0.928	Jul 20, 1998	Oct 19, 1998
Mexico	0.418	0.000	0.010	0.872	May 14, 1998	Aug 11, 1998
Iceland	0.043	0.546	0.042	0.585	Jul 29, 1997	Nov 5, 1998
Turkey	0.100	0.277	-0.012	0.871	Jul 6, 1998	Jan 13, 1999

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