Measuring Financial Contagion Using Time-Aligned Data: The Importance of the Speed of Transmission of Shocks[*]

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Abstract

This paper presents a new empirical approach to address the problem of trading time differences between markets in studies of financial contagion. In contrast to end-of-business-day data common to most contagion studies, we employ price observations, which are exactly aligned in time to correct for time-zone and end-of-business-day differences between markets. Additionally, we allow for time lags between price observations in order to test the assumption that the shock is not immediately transmitted from one market to the other. Our analysis of the financial turmoil surrounding the Asian crisis reveals that such corrections have an important bearing on the evidence for contagion, independent of the employed methodology. Using a correlation-based test, we find more contagion the faster we assume the shock to be transmitted.

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Keywords: Contagion, Financial crisis, Time-aligned data, Time zone alignment, Speed of transmission.

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I. Introduction

During the last three decades, financial markets have experienced a large number of crises ranging from early crises such as the Latin American debt crisis in the mid 1980s, the US stock market crash in 1987, or the EMS crisis in 1992, to the Mexican crisis in 1994-5 and the Asian and Russian crises in 1997-8 and most recently to crises in Turkey in 2000-1, Argentina in 2001 and Brazil in 1999 and 2002. These crises have raised questions regarding the transmission of shocks from one national market to the next and the stability or shifts in these transmission channels during a crisis and thus triggered a discussion of the effects of and policy responses to international financial integration. Central to the discussion of crisis transmission channels is the distinction between *interdependence* and *contagion*: If crises are transmitted to interdependent countries through real and stable linkages such as export-import relations, then the spread of a crisis can be limited and countries with good economic fundamentals will be protected. On the other hand, if crises are contagious in the sense that speculative attacks, financial panic, or herd behavior are the transmission forces, then crises will spread further and national policy makers will face difficulties in protecting their markets from such a crisis.[*]

Despite the substantial volume of academic evidence regarding contagion, it is difficult to draw a clear conclusion. The conceptual definitions of contagion differ and the empirical analyses are only partly comparable as methodologies, time periods and financial markets vary substantially across studies. More recently, however Pericoli and Sbracia (2003) and Dungey et al. (2005a, 2005b) have started to compare existing models and to provide a unified approach for contagion tests. Next to highlighting the differences and similarities of the

[*] See Pericoli and Sbracia (2003) for a detailed discussion regarding the definitions of contagion currently in use in the literature, the transmission channels of shocks, and an overview of the empirical evidence.

various methodologies, the latter authors also point out practical problems regarding contagion tests. One of these concerns is *time zone alignment,* which is needed when the actual trading hours differ across markets.† In particular when testing for contagion in equity markets using correlation-based methodology, most studies employ *synchronized data* based on closing prices in two markets, which on a global time scale refer to different points in time. This difference is driven by differences in closing times of markets as well as by differences in time zones. Assuming for example that global financial markets are not fully and equally efficient, one can argue that shocks need time to be transmitted from one market to the other. This *speed of transmission of shocks* might well differ across markets. Thus, contagion studies using synchronized data make strong as well as differing assumptions about the speed of transmission of shocks. For example, the effective time difference of closing prices between Thailand and Taiwan is five hours, compared to only one hour between Thailand and Singapore. For the Asian crisis therefore, the assumed speed of transmission of shocks towards Singapore is five times faster than the assumed speed of transmission of shocks towards Taiwan. If such differences affect the conclusions regarding contagion versus interdependence, then the previously reported variations in results across countries might well be caused by the differences in the speed of transmission implicitly assumed when using synchronized data. Putting it differently, are the conclusions regarding contagion versus interdependence robust to changes in the assumed speed of transmission of shocks?‡

Our study answers this question and proposes a new empirical solution which is applicable when closing times differ but trading hours overlap. As an improvement to the

† To remedy this problem, different methodological solutions have been proposed including moving average returns (Forbes and Rigobon, 2002), lags (Bae et al., 2003), or dummy variables (Kaminsky and Reinhart, 2003).

‡ We are grateful to the referee for suggesting a focus on this research question.

rather simple moving average returns that Martens and Poon (2001) have shown to be inappropriate for the purpose of correlation estimation, Dungey et al. (2005b) propose a simulation approach, which is inspired by the work of Gourieroux et al. (1993). They first simulate high-frequency observations from the available discrete data for one market and then sample from this simulated data such that the observation coincides with an observed data-point for the other market. The availability of high frequency data for equity markets allows us to sample from intra-day data directly thereby relying on observed rather than simulated market dynamics. We term our new approach *time alignment of data*. More specifically, in a first step we generate pairwise *exactly time-aligned* stock market data by matching index values of different markets at the same point in time.[§] In our terminology, an exact time-alignment of data implies that shocks are immediately transmitted. However, such an infinitely high speed of transmission of shocks might not be the appropriate one that can be considered contagious. Therefore, we extend our analysis and allow for time differences between observations to account for a slower speed of transmission. Our results therefore demonstrate the sensitivity of the contagion-versus-interdependence conclusion to the assumed speed of transmission of shocks.

For illustration, we apply our time-alignment-of-data approach to the Asian crisis of July 1997. Whereas our new approach addresses a general problem in correlation studies, our findings serve as a robustness check of the work of King and Wadhwani (1990), Lee and Kim (1993), Calvo and Reinhart (1996), Baig and Goldfain (1999), Forbes and Rigobon (2002) and Corsetti et al. (2005). We calculate conditional and unconditional correlation coefficients for 15 countries during the episode of financial turmoil surrounding the Asian crisis. We compare

[§] Among others, Martens and Poon (2001) refer to this as ‘synchronous’ data.

results for synchronized data, exactly time-aligned data and time-aligned data that allow for a slower speed of transmission of shocks. Our results indicate that an assumed high speed of transmission of shocks favors contagion and a low speed of transmission favors interdependence. Consequently, existing contagion studies based on synchronized data do not allow proper cross-country comparisons and their results are not necessarily robust to changes in the assumed speed of transmission of shocks.

The remainder of this study is organized as follows. Section II briefly summarizes the evidence and development of correlation-based contagion testing before introducing our set-up and deriving an alternative way of measuring contagion. Section III outlines the construction of the synchronized and time-aligned return data. In Section IV, we first discuss the correlation dynamics and contagion-versus-interdependence results from exactly time-aligned correlation coefficients in contrast to synchronized correlation coefficients. Second, we illustrate the sensitivity of the results to different speeds of transmission of shocks. Section V concludes.

II. Correlation-based contagion tests

Early studies of contagion apply simple unadjusted cross-market correlation coefficients, so-called conditional correlation coefficients. In these studies, the findings overwhelmingly point in the direction of contagion. For instance, King and Wadhwani (1990) test for an increase in cross-market correlations between the US, UK and Japan and find that correlations increase significantly after the US stock market crash. Lee and Kim (1993) extend the analysis to 12 major markets and find further evidence of contagion. Calvo and Reinhart (1996) and Baig and Goldfajn (1999) present evidence for contagion after the 1994 Mexican peso crisis and the

1997 Asian crisis. Cross-market correlations usually increased significantly during the crises period for many of the countries.

Forbes and Rigobon (2002), however, correctly realize that these conditional correlation coefficients overestimate the actual cross-market relationships in particular during periods of high volatility. They demonstrate that the presence of heteroskedasticity in market returns can have a significant impact on estimates of cross-market correlations. Therefore, if market volatility increases during crises, any test will overstate the magnitude of cross-market relationships. Thus these tests suggest that contagion occurs even if the underlying propagation mechanism is constant and shift-contagion does not occur. Forbes and Rigobon (2002) use daily data for stock indices of 28 developed and emerging countries to test for evidence of contagion during the 1987 US stock market crash, the 1994 Mexican peso crisis and the 1997 Asian crisis. They show that correlation coefficients for multi-country returns are not significantly higher during crisis periods when changes in the variance of residuals are properly corrected. As a remedy for this overestimation problem, the authors thus propose the use of corrected 'unconditional' correlation coefficients. Applying these to the three crisis periods reveals strong evidence of 'no contagion, only interdependence': The large cross-market linkages after a shock are simply a continuation of strong transmission mechanisms that exist in more stable periods. In response to Forbes and Rigobon (2002), Corsetti et al. (2005) demonstrate that the 'no contagion, only interdependence' result can be attributed to arbitrary assumptions about the variance of the market-specific noise in the country where the crisis originated. These assumptions bias the test towards the null hypothesis of interdependence. For plausible values of the variance of country-specific shocks in Hong Kong, they find evidence of contagion to the stock markets in Singapore, the Philippines, France, Italy and the UK.

While addressing the issue of volatility changes correctly, these two studies adjust only inadequately for the time zone alignment problem as the moving average filter applied to closing prices 'may mask some of the movements in asset prices' (see Dungey et al., 2005b). In contrast, our time-alignment-of-data approach provides an empirical solution based on the true underlying asset return dynamics without potentially introducing the problem of spurious dynamics into the relationship among market returns. More specifically, we calculate correlation coefficients based on exactly time-aligned as well as synchronized return data for 15 countries in the period surrounding the Asian crisis. We are thus able to illustrate the consequences of both, the overestimation problem of Forbes and Rigobon (2002) and the time zone alignment problem of Dungey et al. (2005b), as well as the speed of transmission problem.

Following Forbes and Rigobon (2002) and Corsetti et al. (2005), we examine the relationship between returns in different markets by using a simple linear model:

$$r_{i,t} = \beta r_{j,t} + \varepsilon_t \tag{1}$$

where j denotes the ground-zero country in which the crisis originates – Thailand in our case – and i denotes the country into which the crisis might – or might not – have spilled over.[**] Therefore, a significant change in the relationship between the returns, as given by a change in β, is evidence for contagion. Essentially, we are testing for a statistical change in the correlation coefficient ρ_i between the stock market returns of country i and ground-zero country j. For periods of high volatility, such as crisis periods, this implies first, that ρ_i will

[**] We also assume that the correlation between $r_{j,t}$ and ε_t is zero and that the variance of ε is a constant k.

increase as volatility increases and second, that ρ_i will overestimate the actual correlation. To avoid this overestimation problem, Forbes and Rigobon (2002) introduce a simple correction:

$$\rho_i^* = \frac{\rho_i}{\sqrt{1+\delta[1-(\rho_i)^2]}} \tag{2}$$

where δ reflects the relative increase in the variance σ_j of ground-zero country's return r_j measured for two time periods, the high-volatility crisis period (h) and low-volatility stable period (l) as defined in equation (3):

$$\delta = \frac{\sigma_j^h}{\sigma_j^l} - 1 \tag{3}$$

Testing for contagion centers on the null-hypothesis of interdependence, which compares the correlation coefficient in the stable, low-volatility period ρ_i^l with the adjusted correlation coefficient in the high-volatility crisis period ρ_i^{h*}. In particular, we follow Corsetti et al. (2005) who assume that both correlation coefficients are based on return-samples drawn from independent bivariate normal distributions with the same true underlying correlation coefficient. Thus for the crisis as well as pre-crisis correlation coefficient, we can perform a Fisher z-transformation, which is in general defined as

$$z(\rho_i) = \frac{1}{2} \ln\left(\frac{1+\rho_i}{1-\rho_i}\right) \tag{4}$$

Consequently, a standard two-sample t-test of the significance between the adjusted crisis correlation coefficient ρ_i^{h*} and the pre-crisis correlation coefficient ρ_i^{l} can be performed (e.g. see Dungey et al., 2005a).

It is a well-known fact that the ‘no contagion, only interdependence’ result of Forbes and Rigobon (2002) is due to the poor size properties of their methodology. Among others, Dungey et al. (2005a, 2005b) show that the two-sample t-test is biased. Given that typically the pre-crisis sample is large and the crisis sample is small, this test has very little power. As a result, the ability of rejecting the null hypothesis is seriously affected by the sample size. In order to deal with this power and size problem, we extend our analysis in two different ways:

Firstly, based on a Monte Carlo study, Dungey and Zhumabekova (2001) confirm that ‘with rapidly increasing standard errors associated with decreasing sample size the chances of rejecting the null hypothesis become vanishingly small’. To overcome this *power problem*, they propose to increase the sample size of the crisis period. They find contagion in 6 out of 9 cases for the longer crisis period. In contrast, they find no evidence of contagion for the short crisis period of Forbes and Rigobon due to the poor power properties of the test statistic. In line with Dungey and Zhumabekova (2001), we therefore consider a short but also a long crisis period.

Secondly, despite the longer crisis period, the approach proposed in Dungey and Zhumabekova (2001) merely demonstrates the impact of the Fisher adjustment. However, by extending the crisis period we implicitly make the assumption that the crisis-period variance is constant over the longer period.[††] Hence this approach is somewhat ad hoc and the issue of the critical values - on the tests of whether correlation has changed or not - has not been fully resolved. We overcome this problem by using a bootstrapping technique to construct the critical values of the test (see Efron and Tibshirani, 1986; Efron, 1988) rather than assuming bivariate normality of the data. We sample pairs of market returns from the pre-crisis (n_l) and the crisis sample (n_h). From this bootstrapped sample, we calculate a pre-crisis correlation ρ_i^l and a crisis correlation ρ_i^h before correcting the crisis correlation according to equation (2). Finally, we obtain a test statistic by calculating the difference between the adjusted crisis correlation $\rho_{i,m=1}^{h*}$ and pre-crisis correlation $\rho_{i,m=1}^{l}$. We repeat the procedure 5000 times (m=1 to 5000) and obtain our critical values for 1% and 5% from the histogram of test statistics. Consequently, a test of the significance between the adjusted crisis correlation coefficient and the pre-crisis correlation coefficient can be performed. We can reject the null-hypothesis of interdependence if the calculated value for $[\rho_i^{h*} - \rho_i^l]$ is larger than the bootstrapped critical value.[‡‡]

Whereas the use of an adjusted correlation coefficient addresses the overestimation problem and the use of a bootstrapping technique as well as the use a longer crisis period address the power and size problem, the potential bias introduced by the use of synchronized data has not been investigated yet. Thus, the existing studies make strong as well as differing assumptions about the speed of transmission of shocks due to differences in closing time and/or differences in time zones. If such differences affect the conclusions regarding contagion versus interdependence, then the previously reported variations in results across countries might well be caused by the differences in the assumed speed of transmission. We

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[††] We are again grateful to the referee for drawing our attention to this issue.

[‡‡] Notice that the standard test relies on bivariate normality of the data. The difference between the Fisher-transformed correlations, $z(\rho_i^{h*})$ and $z(\rho_i^l)$, is assumed to be normally distributed and we can reject the null-hypothesis of interdependence if the calculated value for $[z(\rho_i^{h*})-z(\rho_i^l)]$ is larger than the critical value under normality. The parametric approach is known to result in somewhat wider confidence intervals than those obtained by our bootstrapping method (see e.g. Rasmussen, 1987).

therefore illustrate how robust the results are to changes in the assumed speed of transmission of shocks.

III. Data

To illustrate the effects of using time-aligned data, we apply our methodology to different phases of the Asian crisis of 1997. We define Thailand's decision to float their currency on July 2, 1997 as the decisive event for this crisis. Consequently, Thailand constitutes our ground-zero country j from which the crisis potentially spilled over into other countries. We identify the low-volatility period as a pre-crisis period, which ranges from January 1, 1996 until the day before the start of the crisis period. In particular, we consider two different phases of the Asian crisis. Whereas the Asian crisis started in the currency markets at the beginning of July 1997, its effects were not felt in the stock markets until the end of the month. Having increased sharply during the last week of June, the Thai stock market index remained between 600 and 700 during the month of July and revealed an overall positive trend. The market reached its peak on July 29 with a closing index of 679.2. However, during the period July 30 until September 2, the market lost nearly 28% of its value. Thus, we consider a first early crisis phase to range from July 30 to September 2. In the remainder of this paper we refer to this phase of the Asian crisis as the 'Thailand crisis'. In addition, we consider a second, late crisis phase ranging from October 17 to November 16. Here we follow Forbes and Rigobon (2002) and Corsetti et al. (2005) who consider the importance of the 25% fall of Hong Kong's stock market during the Asian crisis. Consequently, we will refer to this phase of the Asian crisis as the 'Hong Kong crisis'. For our ground-zero country Thailand, this second phase of the Asian crisis followed after the Thai stock market had stabilized somewhat at an index level of 500 to 550 during September and October. During the months following October 17, however, the market lost another 17.5% in value finally closing the year at 372.69 on December 31. For both, the Thailand crisis and the Hong Kong crisis, we take Dungey and Zhumabekova's (2001) criticism into account and extend our crisis periods to 2.5 months. For the Thailand crisis, we thus consider a second, extended crisis period ranging from July 30 to October 16, so as not to overlap with the subsequent Hong Kong crisis. For the Hong Kong crisis, we choose an equally long, extended crisis period from October 17 to December 30.

Starting with Thailand as the ground-zero country, we select 10 Asian countries including Hong Kong, Indonesia, Japan, Korea, Malaysia, the Philippines, Singapore, Taiwan and China, four European countries including France, Germany, Switzerland and the United Kingdom as well as Australia as potential candidates for contagion. Note that in order to investigate time-aligned correlations, we can only focus on stock markets for which trading hours overlap with the trading hours of the Thai market. This prerequisite excludes North and Latin American countries; countries, which are included in other contagion studies.

For Australia and the Asian countries, we collect daily, local currency, closing prices of their major market index from DataStream. For the European countries, we collect 10 o'clock (UK time) prices of their major market index also from DataStream. For ground-zero country Thailand, tick-by-tick data for the Thai market index is purchased from The Stock Exchange of Thailand. Details for these series are given in Table 1. To create pairs of time-aligned stock market returns between each of the 14 countries and Thailand, we first determine the exact time at which the national index is calculated. Since the Thai market is still open at the closing times of the Australian and Asian markets, a time-aligned price-match based on the local closing price can easily be found. Due to the large time-zone difference of at least six hours between Thailand and Europe, however, the Thai market is no longer open when Europe's markets are closing. We therefore revert to the use of stock market indices at 10.00 o'clock UK time provided by DataStream. In this process we are careful to allow for changes in national trading hours and thus the timing of the index's closing price, for time zones and here i.e. national differences in the application of daylight saving time. The countries observing daylight saving time in our sample are the European countries and Australia (Sydney). Note that in autumn 1996 the rule of changing from standard time to daylight saving time changed. A new rule[§§] is now valid for central Europe including the UK: On the last Sunday of March the standard time is changed to daylight saving time and on the last Sunday of October the time is changed back to standard time. In general, the time differences between the countries in our sample and Thailand are determined using the `tz` time zone database. The database contains code and data that represent the history of local time for many representative locations around the world. Most web pages or time zone conversion softwares are using this database. The exact date of change from standard time to daylight saving time was carefully verified with other time zone converters available on the web.

[insert Table 1 about here]

IV. Empirical results

Time alignment generates returns that are different from closing-price returns. Consequently, time-aligned correlations are different from synchronized correlations. As both, pre-crisis as well as crisis returns are different, it is difficult to predict how time-alignment affects the contagion-versus-interdependence conclusion. For the Thailand and Hong Kong crises, Tables

[§§] The rule is a de facto standard, not a law.

2 and 3 report the synchronized correlations in Panel A and exactly time-aligned correlations in Panel B. For many countries, we confirm the findings of Martens and Poon (2001) that synchronized correlations are smaller than exactly time-aligned correlations. During the Thailand crisis this is true for about 50% of our sample while during the Hong Kong crisis the percentage rises to 75%. There are however many markets for which this is not the case. We therefore cannot simply postulate that the transmission of shocks is immediate and that exactly time-aligned correlations provide the true picture of a crisis. Instead we will later consider differences in the speed of transmission of shocks by modeling different degrees of time alignment with time differences ranging from zero to five, 30, 60, and 120 minutes.

Furthermore, we can observe from Tables 2 and 3 that the increase in the correlations due to the time alignment of the data is generally stronger for the crisis periods, i.e. for the long crisis period. Note that the higher crisis correlations are relative to pre-crisis correlations, the more difficult it is to reject the null hypothesis of interdependence. As we find time-aligned correlations to be especially high during crisis periods, we expect to find more contagion for the markets included in our study. The Fisher test as well as the bootstrapped method reflects this conjecture for the long but not for the short crisis period. Looking first at the results for the Thailand crisis in Table 2 reveals that synchronized correlations based on closing prices overwhelmingly indicate interdependence. Only for the case of Thailand versus Indonesia can contagion be found for the long crisis period.[***] For exactly time-aligned data, the case for contagion is stronger. Though only one case of contagion can be found during the short crisis period, six cases of contagion are indicated during the long crisis period: For Australia, Hong Kong, Indonesia, Japan, Malaysia and Singapore the null hypothesis of

[***] In general in Tables 2 and 3, the Fisher test and bootstrapped method lead to the same conclusion regarding contagion and interdependence and differ only in the level of significance.

interdependence can no longer be rejected. These findings of increased evidence of contagion during the long crisis period are in line with Dungey and Zhumabekova (2001) and reflect the low power of the test in small samples, e.g. short crisis periods. For the Hong Kong crisis a similar picture emerges in Table 3. However, there is some evidence for contagion when using synchronized data, i.e. for Korea, the Philippines and Taiwan. In contrast, exactly time-aligned correlations indicate contagion during the long crisis period for Germany, Switzerland, Korea, Malaysia, the Philippines, and Taiwan. Comparing synchronized with exactly time-aligned results shows that various patterns are possible: Markets such as the Philippines or Taiwan that are considered contagious based on synchronized data, also show contagion from Thailand based on exactly time-aligned correlations. Markets such as Germany or Switzerland that are considered interdependent based on synchronized data, show contagion from Thailand based on exactly time-aligned correlations. However, a market such as Korea that shows contagion from Thailand during the short crisis period based on synchronized data, is considered interdependent based on exactly time-aligned correlations. This last pattern is however most likely due to the poor properties of the test for the short crisis period and we thus consider the first two patterns to be representative and dominant – at least for the countries and crises studied here. Furthermore, it is *not* generally true that exactly time-aligned correlations indicate contagion for markets with large time differences in closing times relative to Thailand. For the Thailand crisis phase, for example, no contagion was found for the European markets, which have the largest closing time differences. In sum, we conclude that synchronized data structurally favors interdependence. If the transmission of shocks is immediate and exactly time-aligned correlations reveal the true and correct set of results, there is more evidence for contagion than is so far believed. The under-identification of contagion for the synchronized results can however not be predicted based on closing time differences.

[Insert Tables 2 and 3 about here]

Since we do not know what speed of transmission between markets should be considered contagious, we generate results for differently time-aligned data. In particular, we assume a speed of transmission of five, 30, 60, and 120 minutes. The Fisher test statistic on which our contagion-versus-interdependence conclusion is based is reported in Table 4.[†††] Given the superior power properties of the test statistic for the long crisis period, we only report results for the long crisis periods. Panel A shows the results for the Thailand crisis. Dark (light) grey highlights indicate contagion, e.g. we can reject the null hypothesis of interdependence at the 1% (5%) level. Not highlighted Fisher test statistics indicate interdependence. For the Thailand crisis we find that some markets are interdependent with Thailand at all time alignments. These are the European markets, Korea, the Philippines, Taiwan and China. For the remaining markets, the evidence for contagion weakens as the assumed speed of transmission decreases. For the Hong Kong crisis, similar patterns can be found for some markets: France, the UK, Australia, Hong Kong, Indonesia, Japan, Singapore and China are always interdependent with Thailand. For Germany, Switzerland and Malaysia the evidence for contagion weakens as the assumed speed of transmission decreases. For the remaining markets, however, the Hong Kong crisis reveals new, non-linear patterns: Korea, the Philippines and Taiwan show evidence of contagion which is stable in the case of Korea, strongest for a 60-minute time alignment for the Philippines, and weakest for a 60-minute time alignment for Taiwan. In sum, we therefore have to conclude that (i) a higher assumed speed of transmission generally leads to more evidence for contagion but (ii) this pattern is stronger for the Thailand crisis than for the Hong Kong crisis. A careful identification of the proper time-alignment is therefore essential before starting any study on crisis contagion or interdependence.

[Insert Table 4 about here]

V. Conclusions

This paper presents a new empirical approach to overcome the problem of time zone alignment in correlation studies of financial contagion. Our new *time-alignment-of-data approach* allows us to test the impact of the speed of transmission on the contagion results. We generate pairwise exactly time-aligned stock market data by matching index values of different markets at the same point in time. In contrast to existing studies that use synchronized data such as Forbes and Rigobon (2002) and Corsetti et al. (2005), our method provides an empirical solution based on the true underlying asset return dynamics without potentially introducing the problem of spurious dynamics into the relationship among market returns. We apply our approach to the episodes of financial turmoil surrounding the Asian crisis and test for contagion based on exactly time-aligned as well as synchronized data for 15 countries. Our results suggest that the fundamental difference in the data does ultimately affect the conclusions regarding contagion versus interdependence. Overall, using synchronized rather than exactly time-aligned correlations leads to an under-identification of contagion. Furthermore and more importantly, the contagion-versus-interdependency conclusion is

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††† When using the bootstrapped method, we find similar patterns that differ only in level of significance. Only in 6 of 50 cases the null hypothesis can not be rejected when the bootstrapped method is used instead of the Fisher

indeed dependent on the assumed speed of transmission of shocks. In general, we show that a faster speed of transmission of shocks favors the contagion conclusion whereas a slower speed of transmission of shocks favors the interdependence conclusion. Based on our findings for the long crisis periods using bootstrapped critical values, we reject Forbes and Rigobon (2002)'s claim of 'no contagion, only interdependence'. Given the differences in the time-aligned versus synchronized results, our findings should caution researchers and practitioners alike when drawing conclusions based on synchronized data.

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test. In all other cases, the Fisher test and the bootstrapped method lead to the same conclusion.

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TABLE 1

Sample description

Region	*Country*	*Stock market index*	*Time of index calculation (in local time)*	*Closing time difference during crisis (in hours)*
Ground-zero	Thailand	SET	before 1/2/96 at 4.30 pm, after 1/2/96 at 5.00 pm‡	
Europe	France	CAC40	5.00 pm‡ (10.00 am UK†)	5 or 6
	Germany	DAX30	5.00 pm‡ (10.00 am UK†)	5 or 6
	Switzerland	Swiss Market Index	5.00 pm‡ (10.00 am UK†)	5 or 6
	UK	FTSE100	4.00 pm‡ (10.00 am UK†)	5 or 6
Australia	Australia	All Ordinaries	5.00 pm Sydney time	3 or 4
Asia	Hong Kong	Hang Seng	before 2/1/98 at 3.55 pm, after 2/1/98 at 4.00 pm	2
	Indonesia	Jakarta SE Composite	4.00 pm	1
	Japan	Nikkei 500	3.00 pm	4
	Korea	KOSPI 200	3.00 pm	4
	Malaysia	Kuala Lumpur Composite	5.00 pm	1
	Philippines	Philippines SE Composite	before 2/19/02 at 2.00 pm, after 2/19/02 at 2.30 pm	4
	Singapore	Singapore All Sing Equities	5.00 pm	1
	Taiwan	Taiwan SE Weighted	before 4/4/98 at 12.00 pm, after 4/4/98 at 1.30 pm	5
	China	Shanghai SE Composite	4.00 pm	2

Notes: This table reports all countries included in our analysis, the stock market index chosen to represent the country's stock market and the local time when the index is calculated. Dates are given as month/day/year. SE is the abbreviation for stock exchange. Multiple closing times during the crisis period for European and Australian markets are due different rules regarding daylight saving time before and after October 24, 2007. † For time-aligned analysis only. ‡ For synchronized analysis only.

TABLE 2

Contagion versus interdependence during the Thailand crisis

Country i	Pre-crisis period ρ_i^l	Short crisis period ρ_i^{h*}	Short crisis period Contagion: Fisher test	Short crisis period Contagion: Boot-strapped	Long crisis period ρ_i^{h*}	Long crisis period Contagion: Fisher test	Long crisis period Contagion: Boot-strapped
Panel A: Synchronized data using closing prices							
France	0.0338	0.3041	I	I	0.2019	I	I
Germany	0.0469	0.1939	I	I	0.1265	I	I
Switzerland	0.0540	0.2632	I	I	0.1397	I	I
UK	0.0604	0.2473	I	I	0.0512	I	I
Australia	0.0734	-0.0822	I	I	0.1437	I	I
Hong Kong	0.1017	0.1885	I	I	0.1460	I	I
Indonesia	0.1369	0.3990	I	I	0.4465	C**	C*
Japan	0.0147	0.3509	I	I	0.2242	I	I
Korea	0.0137	0.1638	I	I	0.0036	I	I
Malaysia	0.0943	0.0783	I	I	0.2719	I	I
Philippines	-0.0188	0.1528	I	I	0.1494	I	I
Singapore	0.1607	0.1023	I	I	0.2855	I	I
Taiwan	0.0320	-0.1726	I	I	-0.1865	I	I
China	0.0395	-0.0598	I	I	0.0010	I	I
Panel B: Exactly time-aligned data using matched intra-day prices							
France	0.0969	0.1294	I	I	0.0778	I	I
Germany	0.0678	0.1596	I	I	0.1010	I	I
Switzerland	0.0857	0.1812	I	I	0.1205	I	I
UK	0.1492	0.1848	I	I	0.0143	I	I
Australia	0.1211	0.0101	I	I	0.2525	C*	C*
Hong Kong	0.1582	0.1950	I	I	0.3475	C*	C*
Indonesia	0.1647	0.5111	C*	C*	0.5170	C**	C*
Japan	0.0919	0.0973	I	I	0.2247	C*	C*
Korea	0.0127	-0.0307	I	I	-0.1172	I	I
Malaysia	0.0978	0.0763	I	I	0.3172	C*	C*
Philippines	0.0758	0.1615	I	I	0.1766	I	I
Singapore	0.1460	0.0828	I	I	0.3386	C*	C*
Taiwan	0.1167	-0.1459	I	I	-0.1140	I	I
China	0.0179	-0.0178	I	I	-0.0098	I	I

Notes: For each country in our sample, columns 2, 3 and 6 report the pre-crisis correlation coefficients ρ_i^l and the adjusted crisis correlation coefficients ρ_i^{h*} of that country's stock market index with the Thailand index, respectively. In columns 4 and 7 a C is reported when the Fisher 2-sample t-test statistic indicates contagion and an I is reported when this test indicates interdependence. In columns 5 and 8 a C is reported when the bootstrapped method indicates contagion and an I is reported when this method indicates interdependence. Confidences levels are indicated with * for the 5% confidence level and ** for the 1% confidence level. The pre-crisis period ranges from January 4, 1996 to July 29, 1997, the short crisis period ranges from July 30, 1997 to September 2, 1997 and the long crisis period ranges from July 30, 1997 to October 16, 1997.

TABLE 3

Contagion versus interdependence during the Hong Kong crisis

Country i	*Pre-crisis period* ρ_i^l	*Short crisis period* ρ_i^{h*}	*Short crisis period* Contagion: *Fisher test*	*Short crisis period* Contagion: *Boot-strapped*	*Long crisis period* ρ_i^{h*}	*Long crisis period* Contagion: *Fisher test*	*Long crisis period* Contagion: *Boot-strapped*
Panel A: Synchronized data using closing prices							
France	0.0720	0.0453	I	I	0.1112	I	I
Germany	0.0714	0.0729	I	I	0.1429	I	I
Switzerland	0.0795	0.0476	I	I	0.1018	I	I
UK	0.0588	-0.0125	I	I	0.1125	I	I
Australia	0.0902	0.2062	I	I	0.2427	I	I
Hong Kong	0.1201	-0.0024	I	I	0.0890	I	I
Indonesia	0.2409	0.1058	I	I	0.2418	I	I
Japan	0.0648	-0.0275	I	I	0.0551	I	I
Korea	0.0161	0.4287	C*	C*	0.4668	C**	C**
Malaysia	0.1573	0.2022	I	I	0.3504	I	I
Philippines	0.0327	0.2232	I	I	0.3511	C*	C*
Singapore	0.1987	0.1419	I	I	0.2213	I	I
Taiwan	-0.0006	0.2074	I	I	0.2535	C*	C*
China	0.0362	0.2018	I	I	0.1772	I	I
Panel B: Exactly time-aligned data using matched intra-day prices							
France	0.0971	0.1772	I	I	0.2032	I	I
Germany	0.0809	0.2013	I	I	0.2408	C*	C*
Switzerland	0.0982	0.2019	I	I	0.2459	C*	C*
UK	0.1209	0.1572	I	I	0.2241	I	I
Australia	0.1494	0.2064	I	I	0.2158	I	I
Hong Kong	0.1948	0.0196	I	I	0.0797	I	I
Indonesia	0.2744	0.1100	I	I	0.2478	I	I
Japan	0.1266	0.0069	I	I	0.0778	I	I
Korea	-0.0064	0.2815	I	I	0.3589	C**	C*
Malaysia	0.1714	0.1867	I	I	0.3909	C*	C*
Philippines	0.1097	0.1319	I	I	0.3295	C*	C*
Singapore	0.1985	0.1618	I	I	0.2384	I	I
Taiwan	0.0828	0.2942	I	I	0.2652	C*	C*
China	0.0155	0.2358	I	I	0.1546	I	I

Notes: For each country in our sample, columns 2, 3 and 6 report the pre-crisis correlation coefficients ρ_i^l and the adjusted crisis correlation coefficients ρ_i^{h*} of that country's stock market index with the Thailand index, respectively. In columns 4 and 7 a C is reported when the Fisher 2-sample t-test statistic indicates contagion and an I is reported when this test indicates interdependence. In columns 5 and 8 a C is reported when the bootstrapped method indicates contagion and an I is reported when this method indicates interdependence. Confidences levels are indicated with * for the 5% confidence level and ** for the 1% confidence level. The pre-crisis period ranges from January 4, 1996 to October 16, 1997, the short crisis period ranges from October 17, 1997 to November 16, 1997 and the long crisis period ranges from October 17, 1997 to December 30, 1997.

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TABLE 4

Sensitivity of the contagion results to the timing of the data

Country i	Fisher test for differently time-aligned data (time difference between observations in minutes) 0	5	30	60	120	Fisher test for synchro-nized data
	Panel A: Thailand crisis					
France	-0.1315	-0.1569	-0.2492	-0.3549	0.2109	1.1669
Germany	0.2281	0.2014	-0.1184	-0.2279	0.7395	0.5482
Switzerland	0.2400	0.2312	0.1885	0.1655	0.7313	0.5915
UK	-0.9296	-0.9981	-0.8202	-0.7058	0.0764	-0.0636
Australia	1.7331	1.8596	1.9456	1.7014†	0.7097	0.4870
Hong Kong	1.6876†	1.7294	1.9455	2.4211	1.0714	0.3080
Indonesia	2.7782	2.4522	2.2240	1.9547	1.6811	2.3440
Japan	1.9335	1.9216	2.1196	1.7891	0.7261	1.4602
Korea	-0.8926	-0.6836	-0.4223	-0.3450	-0.1826	-0.0695
Malaysia	1.7751	1.7890	1.9626	1.6695†	0.4716	1.2614
Philippines	0.7017	-0.5397	-0.0607	1.5828	1.2828	1.1587
Singapore	1.9063	2.0499	1.7370†	1.5423	1.5147	0.9005
Taiwan	-1.5856	-1.0761	-0.4714	-0.4030	-0.8030	-1.5108
China	-0.1891	0.1164	0.3577	0.5331	0.7563	-0.2636
	Panel B: Hong Kong crisis					
France	0.7012	0.6716	0.6215	0.8869	0.2497	0.2550
Germany	1.9728	1.9510	2.0482	1.7414†	0.5215	0.4721
Switzerland	1.8995	1.9396	2.2015	1.9387	0.5433	0.1465
UK	0.6942	0.6432	0.6596	0.5869	0.3264	0.3534
Australia	0.4571	0.5450	0.5765	0.3788	0.7519	1.0459
Hong Kong	-0.7746	-0.7986	-0.7449	-0.8398	-0.6373	-0.2076
Indonesia	-0.1901	-0.1641	-0.3980	-0.5223	-0.5227	0.0064
Japan	-0.3277	-0.3144	-0.3386	-0.1476	0.439	-0.0647
Korea	2.5418	2.6440	2.4494	2.0919	2.3917	3.2590
Malaysia	1.8946	1.7465	1.9979	1.6869†	1.4475	1.5096
Philippines	1.8442	1.7348†	1.9721	2.3556	2.1897	2.2215
Singapore	0.2790	0.2175	0.1334	0.5557	1.1096	0.1570
Taiwan	1.7553	1.8569	1.9214	1.6959	1.7695	1.9279
China	0.9252	0.8713	0.9502	0.9273	0.7870	0.9417

Notes: The table presents the contagion results for differently time-aligned data. We test for different possible speed of transmission of shocks. The assumption is that the appropriate alignment might be contemporaneous (0 minutes), within 5, 30, 60 or 120 minutes. Additionally, the results for closing prices are presented. We report the Fisher 2-sample t-test statistic applied to test the null hypothesis of interdependence. The test statistic is highlighted when the null hypothesis is rejected, e.g. in case of contagion. Confidences levels are indicated in light grey for the 5% level and dark grey for the 1% level. In Panel A for the Thailand crisis, the pre-crisis period ranges from January 4, 1996 to July 29, 1997 and the long crisis period ranges from July 30, 1997 to October 16, 1997. In Panel B for the Hong Kong crisis, the pre-crisis period ranges from January 4, 1996 to October 16, 1997 and the long crisis period ranges from October 17, 1997 to December 30, 1997. † Interdependence cannot be rejected when the bootstrapped method is used to obtain critical values. In all other cases, the Fisher test and the bootstrapped method lead to the same conclusion.