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# Correlation, Contagion, and Asian Evidence\*

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## Abstract

This paper examines the empirical literature on financial market contagion in Asia during the 1997–98 financial crises with respect to existing tests of contagion. Empirical evidence shows that contagion affects both developed and emerging markets and does not seem to vary with the relative fundamental economic health or trade and financial linkages of the Asian economies. Contagion occurs across both asset types and geographical borders and tends to have larger effects in equity markets than in currency and bond markets. There is evidence to support the hypothesis that contagion is regional and transmitted through developed markets. A discussion of the behavior of correlation coefficients in the presence of contagion and financial crises suggests that they are not a reliable metric for detecting contagion.

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## 1. Introduction

Despite a relatively large amount of empirical literature addressing the issue of the existence of contagion between countries and markets during financial crises, there is little consensus on the results. Of course this creates difficulties for policymakers and researchers in assessing whether or not contagion exists and whether it is truly a problem upon which policy should or could be focused. This paper canvases related issues across the literature on contagion in the context of the Asian financial crisis in 1997–98. The Asian crisis focused market participants, policymakers,

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and researchers on the issue of contagion, even though the transmission of financial crises to other countries, such as the 1987 stock market collapse (King and Wadhvani 1990) and the 1994–95 Mexican peso crisis, which spawned the so-called tequila effect (Sachs, Tornell, and Velasco 1996), occurred earlier.

The definition of contagion in the academic literature has been an evolving concept, which has served as an obstacle to reaching a consensus on its relevance in explaining crises. During the Asian financial crisis, contagion was used commonly in the popular press to describe the dramatic spread of the crisis, while academics had many competing definitions. In the last few years, a terminology has developed to distinguish the categories of contagion that are recognized in the existing frameworks for conducting empirical analysis. The major distinction is between fundamentals-based contagion and pure contagion (see Dornbusch, Park, and Claessens 2000; Kaminsky and Reinhart 2000). Fundamentals-based contagion refers to the transmission of shocks between countries or markets routed through real links such as trade, macroeconomic similarities, financial links such as banking linkages and capital flows, or linkages that could have been anticipated *ex ante* the shock to asset markets. Fundamentals-based contagion reflects that a crisis in one country will spill over to other countries based on linkages as a result of normal levels of financial and economic integration.

Pure contagion refers to the transmission of shocks over and above that which occurs through fundamental linkages. In periods of crisis, markets are suddenly more integrated compared to tranquil times.<sup>1</sup> These hypothesized additional linkages include competitive devaluations in which terms-of-trade effects hasten rapid devaluations between economies but are mainly focused on the role of investor behavior. The importance of investor behavior in transmitting contagion across countries is explained in concepts such as wake-up calls, in which market participants focus their attention on countries with fundamental indicators comparable to those in crisis countries; portfolio adjustment or rebalancing, in which accounting and market structures provide incentives for individual portfolio managers to make similar moves at the same time, thus propagating crises between countries (Kodres and Pritsker 2002); herd behavior, in which uncertainty and the possibility of information asymmetries cause investors to follow the crowd (Calvo and Mendoza 2000);

<sup>1</sup> In the extreme case of two markets being fully integrated in tranquil times, if one market experiences a crisis, then the second market will also experience a crisis. In this case there is no role for contagion, as it is expected that both markets will decline. Alternatively, if there is usually no integration between two markets in tranquil times, and a crisis occurs in one market, it is not expected that the second country will experience a crisis. If this second country also experiences a crisis, this suggests contagion.

and wealth effects, which arise from the cumulative effect of investors making losses in one area rushing for liquidity from other areas of their portfolios (Kyle and Xiong 2001).<sup>2</sup> Dungey, Fry, González-Hermosillo, and Martin (2005a) show that many of the distinctions in the definitions of pure contagion in empirical work are nested. During the Asian crisis, the term *contagion* was fairly broadly defined and could mean any or all of these things.

Earlier literature tends to use the term *contagion* to refer to both fundamentals-based and pure contagion effects, such as Eichengreen, Rose, and Wyplosz (1995, 1996). More recently, *contagion* refers principally to pure contagion effects, and fundamentals-based contagion is considered separately and often labeled as *spillovers*, a term due to Masson (1999). The focus on contagion in policymaking and empirical literature revolves around the importance of understanding linkages between financial markets during times of crisis and a recognition that such linkages may change in unexpected ways during periods of turmoil. The optimal policy response to a crisis should differ depending on the relative importance of fundamentals-based or pure contagion, as the underlying causes are presumably quite different. This paper assesses the evidence in the literature as to whether contagion is important in the first place, its characteristics, and whether or not a reaction to it should occur.

Most theoretical models seek to explain why markets appear to be more correlated during a crisis period. The problem is that theoretical concepts explaining contagion are difficult if not impossible to measure empirically, so appealing to the data for some understanding of the underlying reasons for pure contagion is quite challenging. Most empirical models of contagion instead look for contagion by examining the evidence for strengthened linkages during a crisis period. Often this is associated with some form of test for increased correlation among asset returns, although some authors point out that increasing correlation is not necessarily an indication of contagion (Corsetti, Pericoli, and Sbracia 2001, 2005; Forbes and Rigobon 2002; Bekaert, Harvey, and Ng 2005; Dungey, Fry, González-Hermosillo, and Martin 2006b). A number of important overviews of empirical literature exist, including Dornbusch, Park, and Claessens (2000) and Pericoli and Sbracia (2003), with Bekaert and Harvey (2003) providing a particular focus on emerging markets.

Empirical literature, in some instances supported by theory, has raised a number of important propositions about contagion during financial crises. This is augmented by agendas arising from international bodies, such as the 1998 Bank for International Settlements (BIS) survey of market participants following the Russian and

<sup>2</sup> For overviews of these concepts, see Goldstein (1998), Lowell, Neu, and Tong (1998), and Dungey and Tambakis (2005).

long-term capital management (LTCM) crises. These propositions provide a framework for understanding potential policy responses to contagion. Seven such propositions are synthesized below.

1. Strong fundamentals imply immunity to contagion.
2. Trade and financial linkages between countries are associated with contagion transmission.
3. Regional proximity is important in transmitting/receiving contagion effects.
4. Emerging markets experience greater contagion than developed markets.
5. Developed markets operate as a conduit for contagion effects between regions.
6. Contagion effects differ by asset market.
7. Contagion occurs across both asset market and country borders.

The rest of this paper proceeds as follows. Section 2 presents data relating to the Asian financial crisis along with a brief background of events. Section 3 examines issues arising from using changes in correlation as the measure to distinguish crises and contagion in a formal model. The paper then canvases evidence for contagion during the Asian financial crisis from the empirical literature across different asset classes in section 4. Section 5 turns to the seven propositions previously listed to examine evidence as to whether pure contagion is a relatively important influence on asset returns, or alternatively, whether domestic or world/regional influences, including fundamentals-based contagion, are of greater importance. Section 6 provides some concluding comments.

## 2. The crisis in Asia

The events of the 1997–98 Asian crisis have been examined in great detail. Some of the key events of this crisis include the devaluation of the Thai baht in July 1997; the Hong Kong speculative attack of October 1997; the devaluation and float of other Asian currencies during the period; the coordinated rollover of Korea's short-term debt by commercial banks to avoid a debt moratorium in December 1997; the closing or restructuring of financial institutions in most crisis countries including Indonesia, Korea, Malaysia, and Thailand; the imposition of capital controls in Malaysia in 1998; the change of political leadership in all countries excluding Malaysia (although there the deputy prime minister, who also served as the finance minister, was fired); and the dramatic reduction of sovereign ratings for all crisis countries. Indonesia, Thailand, and Korea all sought IMF assistance packages, and many industrial countries pledged financial assistance. For chronologies of the crisis, see Bank for International Settlements (1998), IMF (1999), Kaminsky and Schmukler (1999), Athukorala (2001), and Baur and Fry (2006).

Figures 1 and 2 show daily currency and equity returns for a selection of economies most affected by the crisis over the period. The currency returns are presented from 2 June 1997 to 30 June 1998. Many of the Asian currencies were pegged prior to this date. A longer period is covered in the figures on equity returns, which are shown from 2 January 1996 to 31 July 1998. The figures highlight the speed with which the Asian crisis spread across different asset classes in the Asian economies.

The implications of the lack of consensus on the transmission process in the Asian crisis are evident in the response of national and international policymaking bodies. There were numerous calls for the reform of international financial infrastructure to halt the potential transmission of crises via contagion; for example, Claessens and Forbes (2001), Goldstein (1998), Eichengreen (1999), and Vines and Gilbert (2004). Many of the original proposals focused on reforms to national economic systems through transparency, domestic regulation, improved national economic management, and development of domestic financial markets. This agenda has not been universally popular with the crisis countries, as it puts the burden of adjustment on those countries that have already borne the greatest cost. For example, Radelet and Sachs (1998) and Germain (2002) argue that the crucial change needed post-crisis is to reshape international finance as inclusive of emerging market economies, which is a political agenda rather than a purely economic one.

### 3. Preliminary tests of contagion using correlations

The preliminary work on testing for contagion involved testing for a change in the correlation of asset markets between crisis and noncrisis periods. Early work was by King and Wadhvani (1990) and Baig and Goldfajn (1999). Forbes and Rigobon (2002) are associated with a heteroskedasticity-adjusted correlation test that famously finds little evidence of contagion during a number of financial crises, including from Hong Kong equity markets in 1998.

Figure 3 presents selected rolling correlations between daily equity returns for Hong Kong, Indonesia, Korea, Malaysia, and Thailand surrounding four crisis events. The window width is one month. The four rows of the figure correspond to the four events selected:

1. the Thai baht devaluation of July 1997, with the panel covering 2 June to 31 July 1997;
2. the Hong Kong speculative attack from 1 October 1997 to 14 November 1997;
3. the period surrounding the successful avoidance of the Korean debt moratorium on 24 December 1997, with the figure covering the month of December;
4. the turmoil in Indonesia from 1 January to 27 February 1998.

Figure 1. Local-currency returns against U.S. dollars for Indonesia, Korea, Malaysia, and Thailand for the period 2 June 1997 to 30 June 1998

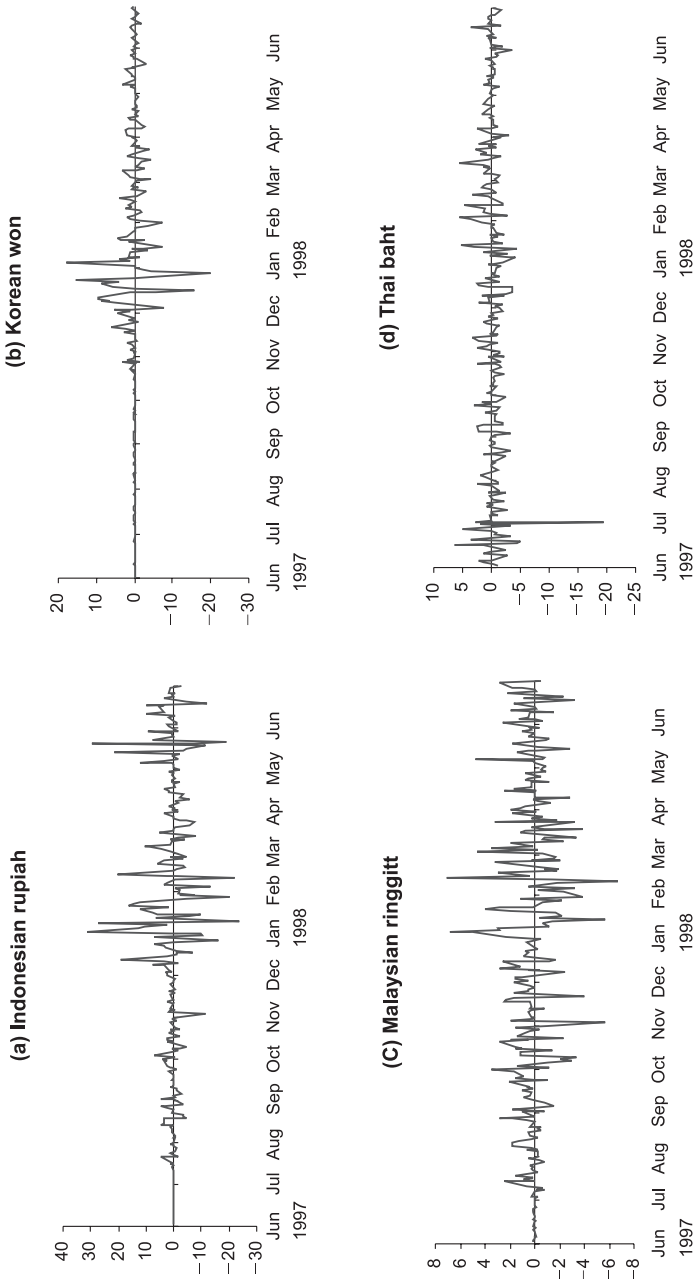
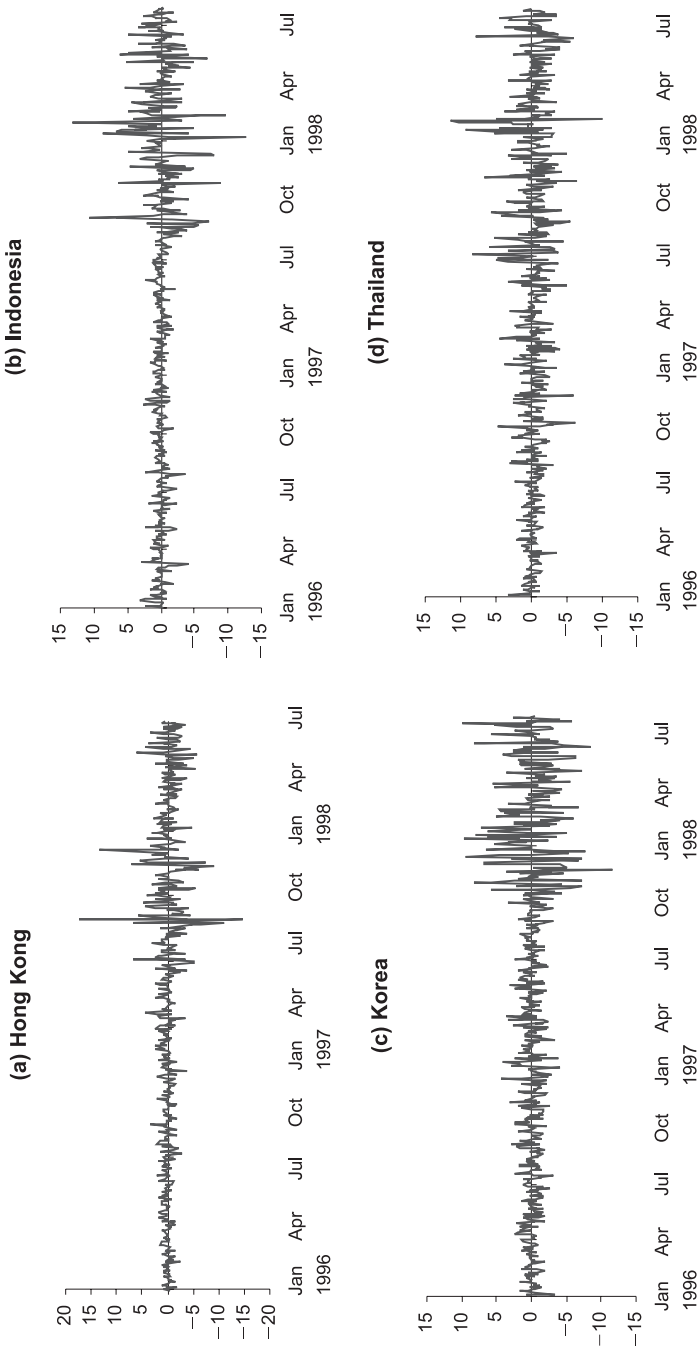
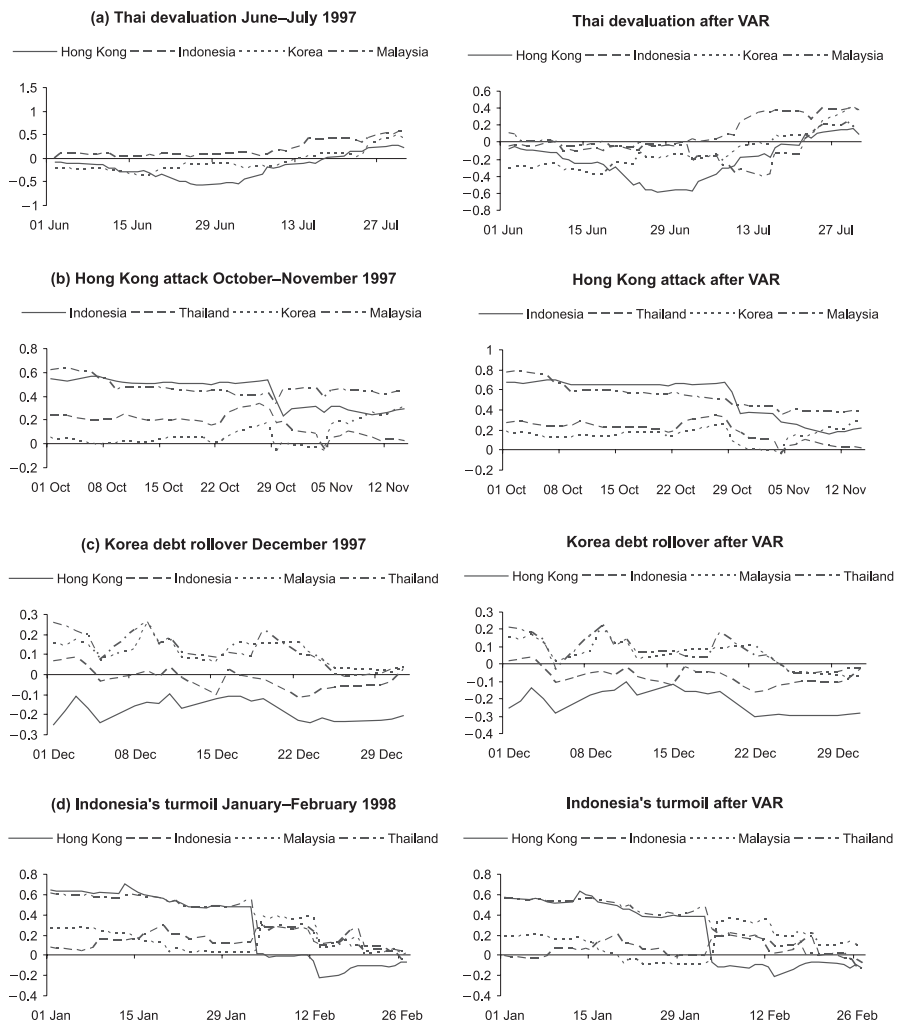


Figure 2. Equity returns data for Hong Kong, Indonesia, Korea, and Thailand for the period 2 January 1996 to 31 July 1998



**Figure 3. Rolling correlations of daily equity returns calculated over a monthly window around four key events**



**Note:** First column based on actual data; second column based on the residuals from a VAR containing all equity returns with one lag. Panel (a) correlation with Thailand, 2 June–31 July 1997; (b) correlation with Hong Kong, 1 October–14 November 1997; (c) correlation with Korea, 1–31 December 1997; (d) correlation with Indonesia, 1 January–27 February 1998.



The first column in the figure presents correlation coefficients calculated on equity returns, and the second presents correlation coefficients calculated on the residuals of a vector autoregression (VAR) model containing all returns with one lag. The correlations of the residuals of the VAR are reported, as tests for contagion such as that proposed by Forbes and Rigobon (2002) attempt to capture fundamental relationships through a VAR, so contagion is identified through the modeling of outliers.

From inspection of Figure 3, it is immediately obvious that the correlations are not stable, either before or after fundamentals are controlled for. More pertinently, it is not clear that correlations necessarily increase after a shock: the Thai baht devaluation is an example in which correlations increase, whereas the Hong Kong shock is an example in which they decrease.

### 3.1 A model of asset returns

To better assess what the correlation analysis presented above might represent in identifying contagion, a financial market model with its origins in the factor models of arbitrage pricing theory is specified (see Sharpe 1964; Solnik 1974). Two periods are distinguished in the model. The first is a factor model in which assets are priced based on “normal” shocks during a noncrisis, or tranquil, period. The second is a factor model which extends the tranquil-period factor model by allowing for additional linkages arising from contagion and various types of structural breaks that potentially arise during financial crises.

**A model for tranquil times** The model in a noncrisis period in the case of three assets consists of a one-factor model in which returns ( $x_{i,t}$ ) are specified as a function of a common factor ( $w_t$ ) and an idiosyncratic component ( $u_{i,t}$ ):

$$x_{i,t} = \lambda_i w_t + \phi_i u_{i,t} \quad i = 1, 2, 3, \quad (1)$$

where for simplicity

$$w_t \sim N(0,1), \quad (2)$$

$$u_{i,t} \sim N(0,1), \quad i = 1, 2, 3, \quad (3)$$

are assumed to be independent. For simplicity, all returns are assumed to be demeaned, in which case there is no need for a constant term in (1). The common factor captures market fundamentals or systematic risk that has an impact on asset returns with a loading of  $\lambda_i$ . This factor is also interpreted as a measure of integration.

The idiosyncratic components capture those periods in which returns deviate from their market fundamentals and have an impact on asset returns with a loading of  $\phi_i$ . In the special case in which  $\lambda_1 = \lambda_2 = \lambda_3 = 0$ , the markets are segmented with volatility in asset returns, which are driven entirely by their respective idiosyncratic components. The assumption that the world and idiosyncratics are distributed as  $N(0,1)$  can be relaxed by including autocorrelation and conditional volatility in the form of generalized autoregressive conditional heteroskedasticity (GARCH), as in Dungey, Fry, and Martin (2003).

**Estimation issues** The assumption that the common factor ( $w_t$ ) and the idiosyncratic factors ( $u_{i,t}$ ) are independent implies that the volatility of returns as measured by the variance is obtained by squaring both sides of (1) and taking expectations:

$$E[x_{i,t}^2] = \lambda_i^2 + \phi_i^2, \quad i = 1, 2, 3. \quad (4)$$

This expression shows that the variance of returns can be conveniently decomposed into two components: the contribution from the common factor ( $\lambda_i^2$ ) and the contribution from the idiosyncratic factor ( $\phi_i^2$ ). An important advantage of this expression is that it makes it possible to provide an estimate of the average relative contributions of the two factors to the volatility of returns during tranquil periods.

Similarly, the covariance between returns during periods of tranquility is obtained from (1) by multiplying  $x_{i,t}$  by  $x_{j,t}$  and taking expectations:

$$E[x_{i,t}x_{j,t}] = \lambda_i\lambda_j, \quad \forall i \neq j. \quad (5)$$

During tranquil periods, co-movements in returns are solely determined by the common factors, with no role played by the idiosyncratic factors. For asset returns that are affected by the common factor in the same direction, that is, for which the loading parameters have the same sign, the returns on these assets move in the same direction on average. For asset returns that are affected by the common factor in opposite directions, that is, for which the loading parameters are not the same sign, the returns move in opposite directions on average.

The expressions for the variance in (4) and covariance in (5) suggest that a natural way to estimate the six parameters of the tranquil model,

$$\{\lambda_1, \lambda_2, \lambda_3, \phi_1, \phi_2, \phi_3\}, \quad (6)$$

is to equate the theoretical moments in (4) and (5) with the respective empirical moments. For a sample of size  $T$ , the pertinent set of equations that needs to be solved is

$$\begin{aligned} s_{11} &= \hat{\lambda}_1^2 + \hat{\phi}_1^2, & s_{22} &= \hat{\lambda}_2^2 + \hat{\phi}_2^2, & s_{33} &= \hat{\lambda}_3^2 + \hat{\phi}_3^2, \\ s_{12} &= \hat{\lambda}_1 \hat{\lambda}_2, & s_{13} &= \hat{\lambda}_1 \hat{\lambda}_3, & s_{23} &= \hat{\lambda}_2 \hat{\lambda}_3, \end{aligned} \tag{7}$$

where a  $\hat{\phantom{a}}$  denotes an estimator and

$$s_{ij} = \frac{1}{T} \sum_{t=1}^T x_{i,t} x_{j,t} \tag{8}$$

represents the sample covariance (empirical moment) between assets  $i$  and  $j$ . This is a system of six equations and six unknowns that can be solved to provide estimates of the parameters. Formally, estimation proceeds using a generalized method of moments (GMM) estimator. As the system is in this case just identified, as the number of unknown parameters matches the number of equations, it is possible to derive the following analytical expressions for the estimators:

$$\begin{aligned} \hat{\lambda}_1^2 &= \frac{S_{12}S_{13}}{S_{23}}, & \hat{\lambda}_2^2 &= \frac{S_{12}S_{23}}{S_{13}}, & \hat{\lambda}_3^2 &= \frac{S_{13}S_{23}}{S_{12}}, \\ \hat{\phi}_1^2 &= \frac{S_{11}S_{23} - S_{12}S_{13}}{S_{23}}, & \hat{\phi}_2^2 &= \frac{S_{22}S_{13} - S_{12}S_{23}}{S_{13}}, & \hat{\phi}_3^2 &= \frac{S_{33}S_{12} - S_{13}S_{23}}{S_{12}}. \end{aligned} \tag{9}$$

**A model for crisis times** Crisis period relationships can be accounted for by extending the noncrisis model in (1) to (3) by allowing for structural breaks in the world factor and idiosyncratic factors, as well as for increases in asset return volatility from an additional propagation mechanism from one country to another arising from contagion. To distinguish the crisis period from the noncrisis period, returns for the former period are denoted as  $y_{i,t}$ . As before, these returns are also assumed to be demeaned. The factor structure during the crisis period for a trivariate system is specified as

$$y_{1,t} = \lambda_1 w_t + \phi_1 u_{1,t} \tag{10}$$

$$y_{2,t} = \lambda_2 w_t + \phi_2 u_{2,t} + \delta_2 \phi_1 u_{1,t} \tag{11}$$

$$y_{3,t} = \lambda_3 w_t + \phi_3 u_{3,t} + \delta_3 \phi_1 u_{1,t} \tag{12}$$

where

$$w_t \sim N(0, \omega^2), \tag{13}$$

$$u_{i,t} \sim N(0, \kappa_i^2), \quad i = 1, 2, 3. \tag{14}$$

**Structural breaks** If the common factor is interpreted as representing market fundamentals, a change in the pricing of assets during the crisis period as a result of a change in  $w_t$  is captured by the parameter  $\omega^2$  in (13). For  $\omega^2 > 1$ , this leads to an increase in volatility of all asset returns during the crisis period. An alternative form of a structural break, which increases asset market volatility, occurs when there are changes in the idiosyncratic components in the crisis period, with  $\kappa_i^2 > 1$ . It is more typical to model the structural break in the country directly experiencing the crisis, otherwise known as the source country. However, for the crisis to spread from the source country to the other countries in this situation, it is necessary for contagion to exist.

**Contagion** Contagion is defined as shocks originating in the source country over and above the influence of the common factor ( $w_t$ ) which impact the asset returns of the remaining countries. In the case of the crisis model in (10) to (14), country 1 represents the source country, with the strength of contagion to countries 2 and 3 controlled by the parameters  $\delta_2$  and  $\delta_3$ , respectively.

**Estimation issues** Estimation of the parameters of the crisis model proceeds along the lines of that for the tranquil model by adopting a GMM approach whereby the theoretical moments are matched with the empirical moments. As the parameters in (6) are uniquely identified by the tranquil moments, with the solutions given in (9), the remaining parameters in the crisis model,

$$\{\delta_2, \delta_3, \omega, \kappa_1, \kappa_2, \kappa_3\}, \tag{15}$$

are estimated from the following set of equations:

$$\begin{aligned} v_{11} &= \hat{\lambda}_1^2 \hat{\omega}^2 + \hat{\phi}_1^2 \hat{\kappa}_1^2, & v_{22} &= \hat{\lambda}_2^2 \hat{\omega}^2 + \hat{\phi}_2^2 \hat{\kappa}_2^2 + \hat{\delta}_2 \hat{\phi}_1 \hat{\kappa}_1^2, & v_{33} &= \hat{\lambda}_3^2 \hat{\omega}^2 + \hat{\phi}_3^2 \hat{\kappa}_3^2 + \hat{\delta}_3 \hat{\phi}_1 \hat{\kappa}_1^2, \\ v_{12} &= \hat{\lambda}_1 \hat{\lambda}_2 \hat{\omega}^2 + \hat{\delta}_2 \hat{\phi}_1^2 \hat{\kappa}_1^2, & v_{13} &= \hat{\lambda}_1 \hat{\lambda}_3 \hat{\omega}^2 + \hat{\delta}_3 \hat{\phi}_1^2 \hat{\kappa}_1^2, & v_{23} &= \hat{\lambda}_2 \hat{\lambda}_3 \hat{\omega}^2 + \hat{\delta}_2 \hat{\delta}_3 \hat{\phi}_1^2 \hat{\kappa}_1^2, \end{aligned} \tag{16}$$

where, as before, a  $\hat{\cdot}$  denotes an estimator, and

$$v_{ij} = \frac{1}{T} \sum_{t=1}^T y_{i,t} y_{j,t} \tag{17}$$

represents the sample covariance (empirical moment) between assets  $i$  and  $j$  during the crisis period. This is a just-identified system, as there are six equations and six unknowns.

**Changes in correlations** The factor model given above has the advantage that it provides convenient expressions for the correlations between asset returns. Using equations (1) to (3), the correlation between asset 1 and asset 2 during a noncrisis period is

$$\rho_{x_{1,t}x_{2,t}} = \frac{E[x_{1,t}x_{2,t}]}{\sqrt{E[x_{1,t}^2]}E[x_{2,t}^2]}} = \frac{\lambda_1\lambda_2}{\sqrt{\lambda_1^2 + \phi_1^2}\sqrt{\lambda_2^2 + \phi_2^2}}. \quad (18)$$

From equations (10) to (14) the corresponding correlation in the crisis period is

$$\rho_{y_{1,t}y_{2,t}} = \frac{E[y_{1,t}y_{2,t}]}{\sqrt{E[y_{1,t}^2]}E[y_{2,t}^2]}} = \frac{\lambda_1\lambda_2\omega^2 + \delta_2\phi_1^2\kappa_1^2}{\sqrt{\lambda_1^2\omega^2 + \phi_1^2\kappa_1^2}\sqrt{\lambda_2^2\omega^2 + \phi_2^2\kappa_2^2 + \delta_2^2\phi_1^2\kappa_1^2}}. \quad (19)$$

As a number of theoretical and empirical definitions of contagion involve the observation of an increase in correlation coefficients between the noncrisis and crisis periods, it is natural to look at the change in correlation by subtracting (18) from (19):

$$\rho_{y_{1,t}y_{2,t}} - \rho_{x_{1,t}x_{2,t}} = \frac{\lambda_1\lambda_2\omega^2 + \delta_2\phi_1^2\kappa_1^2}{\sqrt{\lambda_1^2\omega^2 + \phi_1^2\kappa_1^2}\sqrt{\lambda_2^2\omega^2 + \phi_2^2\kappa_2^2 + \delta_2^2\phi_1^2\kappa_1^2}} - \frac{\lambda_1\lambda_2}{\sqrt{\lambda_1^2 + \phi_1^2}\sqrt{\lambda_2^2 + \phi_2^2}}. \quad (20)$$

There are several parameters that govern the difference in correlations across the two subperiods. These are  $\delta_i^2$ ,  $\omega^2$ , and  $\kappa_i^2$ , which are now explored. This analysis is closely related to that of Corsetti, Pericoli, and Sbracia (2001, 2005).

### 3.2 Understanding changes in correlations

To understand the underlying relationships governing changes in correlations, equation (20) is computed for various parameterizations. This analysis is based on a simplified version of the model in Dungey, Fry, González-Hermosillo, and Martin (2006b). The parameterized system is

$$y_{1,t} = 4w_t + 2u_{1,t} \quad (21)$$

$$y_{2,t} = 2w_t + 3u_{2,t} + \delta_2 2u_{1,t} \quad (22)$$

$$y_{2,t} = 3w_t + 4u_{2,t} + \delta_3 2u_{1,t} \quad (23)$$

and in this case there are no structural breaks in the common or idiosyncratic factors, so  $\omega^2 = \kappa_i^2 = 1, \quad \forall i$ . In the noncrisis period, the data-generating process for  $x_{i,t}$  is the same as equations (21) to (23) if one sets  $\delta_2 = \delta_3 = 0$  and redefines  $y_{i,t}$  as  $x_{i,t}$ . Figure 4 presents the results of the experiments for the difference in correlations, with all parameters held constant except for one. Panels (a) and (b) explore the behavior of the difference in the correlation coefficients between assets 1 and 2 and assets 2 and 3, respectively, as the strength of contagion  $\delta_i = \delta$  increases. Panels (c) and (d) consider the case in which there is no contagion, but a structural break in the common factor ( $\omega^2$ ).

### Changes in correlation due to contagion

**Asset 1 to asset 3** Panel (a) of Figure 4 shows the change in correlation between  $y_{1,t}$  and  $y_{3,t}$  for increasing values of contagion from  $\delta = 0$  to  $\delta = 20$ , based on equation (20) with  $\omega^2 = \kappa^2 = 1$ . The correlation initially rises but hits a peak and eventually falls and in the limit becomes negative. The initial increase in correlation is consistent with much of the empirical literature, wherein an increase in correlation indicates evidence of contagion. However, the fall in correlation for strong levels of contagion, that is, higher values of  $\delta$ , contradicts the premise that increasing correlation is associated only with contagion. This result casts doubt on empirical evidence that finds no contagion based on nonincreasing correlation.<sup>3</sup>

**Asset 2 to asset 3** Panel (b) of Figure 4 repeats the analysis for  $y_{2,t}$  and  $y_{3,t}$ . This panel appears to provide support for the hypothesis that higher correlation is associated with higher levels of contagion. However, this result is purely spurious, as the increase in correlation is fully generated by a common component, namely,  $u_{1,t}$ . By construction, there are no contagious linkages between assets 2 and 3.

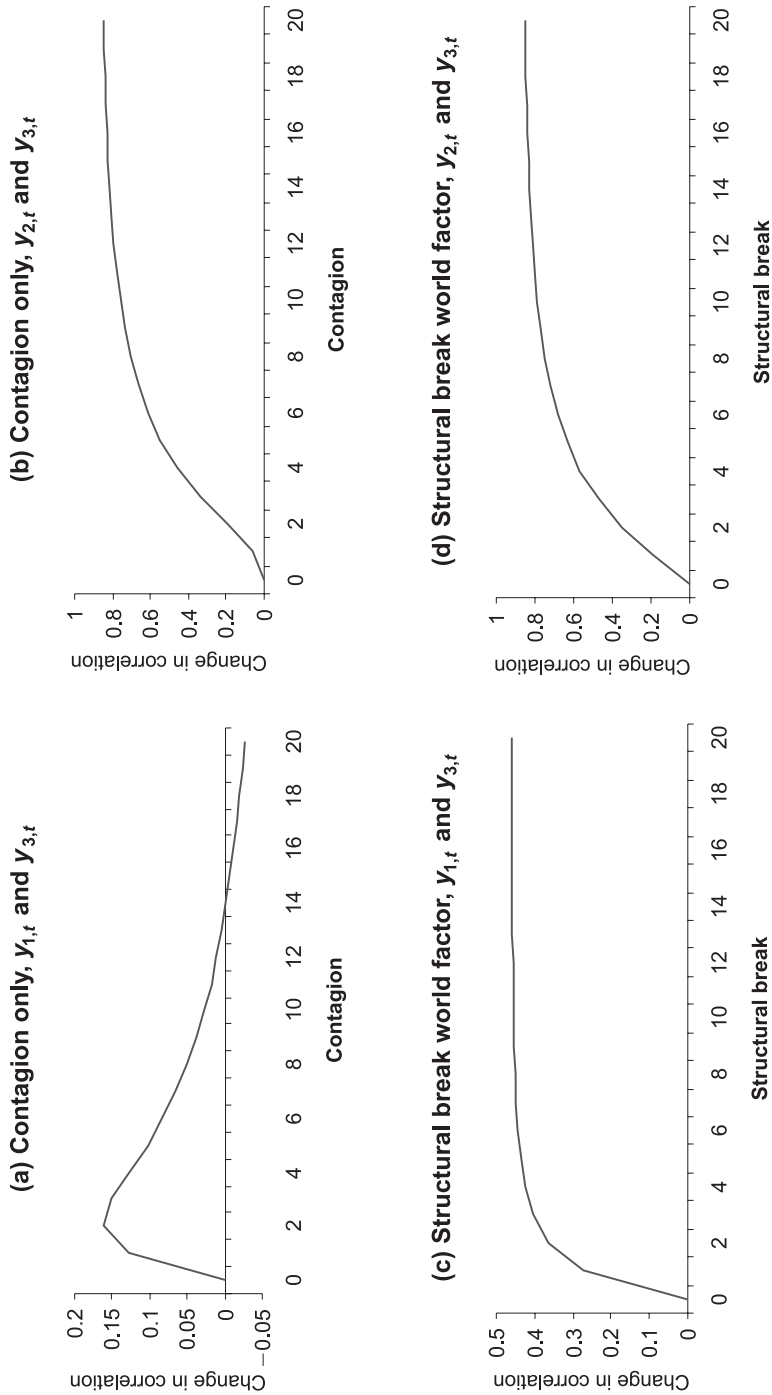
**Changes in correlation due to systemic structural breaks** The effects of increasing systemic shocks ( $\omega^2$ ) on the change in correlations between  $y_{1,t}$  and  $y_{3,t}$  and between  $y_{2,t}$  and  $y_{3,t}$  is given in panel (c) of Figure 4. In this case, there is no contagion ( $\delta = 0$ ) and no idiosyncratic structural break ( $\kappa^2 = 1$ ). Despite the fact that the true process does not involve contagion, there is still an increase in correlation between the two periods. In the limit, the correlation in the crisis period approaches unity,

3 Dungey, Fry, González-Hermosillo, and Martin (2006b) show that (20) yields a fall in correlation for high levels of contagion if

$$\sqrt{1 + \left(\frac{\phi_2}{\lambda_2}\right)^2} < \frac{\lambda_1}{\phi_1}.$$

Corsetti, Pericoli, and Sbracia (2001, 2005) also discuss the problem of measuring contagion via correlation coefficients from this angle in some depth.

Figure 4. Change in correlation coefficients under various contagion and structural break assumptions



reflecting the total domination of the asset returns by the common factor ( $w_i$ ). This result further highlights the danger of misdiagnosing increasing correlation as evidence of contagion. Most applications for tests of contagion specifically assume that the appropriate process describing the data is the presence of contagion and not a structural change in the common factor: for example, Forbes and Rigobon (2002) and Dungey and Martin (2004). Forbes and Rigobon (2001) specifically designate the situation of a structural change in the common factor as shift contagion.

**Relationship with regression analysis** The occurrence of a structural break in the common factor brings out an important relationship between correlation and regression analysis in testing for contagion. To highlight this relationship, consider a special case of the noncrisis and crisis models in (1) to (14) in which  $\phi_1 = 0$ , so country 1 becomes the common factor. From (1) and (10) the asset returns can be expressed in terms of the first asset return. For example, the second asset return equations for the noncrisis and crisis periods are, respectively,

$$\begin{aligned} x_{2,t} &= \frac{\lambda_2}{\lambda_1} x_{1,t} + \phi_2 u_{2,t} = \beta x_{1,t} + \phi_2 u_{2,t} \\ y_{2,t} &= \frac{\lambda_2}{\lambda_1} y_{1,t} + \phi_2 u_{2,t} = \beta y_{1,t} + \phi_2 u_{2,t} \end{aligned} \quad (24)$$

with  $\beta = \lambda_2 / \lambda_1$ , where it is still assumed that there is no contagion ( $\delta_i = \delta = 0$ ) and that there are no idiosyncratic structural breaks ( $\kappa_i^2 = 0$ ). The strength of the transmission mechanism between countries 1 and 2 is given by the parameter  $\beta$ . As this parameter is the same over both noncrisis and crisis periods, it can be estimated by simply regressing the returns of country 2 on the returns of country 1 using the full sample of data, despite the structural break in the common factor.

The fact that the parameter  $\beta$  in (24) is constant over the two sample periods does not imply that the correlations are also constant. To see this, in (20), set  $\phi_1 = \delta_2 = 0$ ,  $\kappa_1 = \kappa_2 = 1$ , so that the change in the correlation between the crisis and noncrisis periods reduces to

$$\rho_{y_{1,t}y_{2,t}} - \rho_{x_{1,t}x_{2,t}} = \frac{1}{\sqrt{1 + \left(\frac{\phi_2}{\lambda_2\omega}\right)^2}} - \frac{1}{\sqrt{1 + \left(\frac{\phi_2}{\lambda_2}\right)^2}}.$$

This expression is positive for  $\omega^2 > 1$ , whereby the structural break in the common factor results in an increase in correlation even though the regression parameter in (24) is constant. This point was first made by Loretan and English (2000) and Forbes



and Rigobon (2002). This result suggests that the stability of the relationship between countries 1 and 2 can be assessed by performing a test of parameter constancy. If the null hypothesis of constant parameters is rejected, this will be evidence of an additional transmission mechanism during the crisis period and hence will constitute contagion. This forms the basis of the regression-based test of contagion suggested by Dungey, Fry, González-Hermosillo, and Martin (2005a).

#### **4. A review of the empirical evidence for Asian financial markets**

Although there are limitations in many of the contagion tests in the suite, as demonstrated by the correlation coefficient example above, some generalities can be extracted from the evidence presented in the empirical literature. Apart from techniques based on correlation analysis, there are several other methodologies by which researchers test empirically for contagion; these methodologies are reviewed in Dungey, Fry, González-Hermosillo, and Martin (2005a). The main empirical tests include those based on modeling outliers from a VAR system, such as that in Favero and Giavazzi (2002); dummy variable-based tests such as that in Pesaran and Pick (2006); and the probability-based measure of Bae, Karolyi, and Stulz (2003), which is related to the previous work of Eichengreen, Rose, and Wyplosz (1995, 1996). Tests based on latent-factor models, such as those examined by the current authors, Corsetti, Pericoli, and Sbracia (2001), and Bekaert, Harvey, and Ng (2005), are also commonly used. Here, evidence is organized by a particular asset market during the crisis period.

##### **4.1 Currency markets**

Contagion during the Asian financial crisis is widely believed to have originated with the float and depreciation of the Thai baht on 2 July 1997. This date is often used in empirical applications to mark the start of the crisis despite the fact that some claim that turmoil was evident in equity markets earlier; see McKibbin and Martin (1998). The problems in dating financial crises are quite pronounced and represent one of the issues which make comparisons of results across empirical studies difficult. Despite the importance of currency markets in the crisis, the literature on testing for contagion in Asian currencies is limited, reflecting the fact that these markets were largely operating under fixed-exchange-rate regimes prior to 1997, making pre-crisis-period volatility comparisons difficult.

Under the alternative hypothesis that the contemporaneous spread of currency crises is consistent with contagion, Glick and Rose (1999), using a large panel of five Asian countries, find that the most important economic linkages explaining these transmissions are trade linkages. Van Rijckeghem and Weder (2001), using a similar

methodology, find that financial links are more important, although they also note that as a result of the close relationship between financial and trade linkages it is difficult to disentangle the two.

Baig and Goldfajn (1999) show a pronounced increase in correlation coefficients during the crisis period as evidence of contagion. However, the effects of this contagion on developed markets in the region is muted; notably both Debelle and Ellis (2005) and Dungey, Fry, and Martin (2004), using an alternative statistical framework, show small effects of contagion to Australia and New Zealand, and the latter paper to Japan.

Substantial contagion effects within the Asian region are revealed in Dungey and Martin (2004). In investigating the links among Malaysia, Indonesia, Korea, and Thailand during 1997–98, Dungey and Martin find statistically significant contagion effects of up to 46 percent of total volatility for Korea, mostly sourced from Thai-based shocks. However, although Thailand is the major source of shocks for Korea and Malaysia, the majority of the effects on Indonesia are transmitted indirectly through Malaysia.

#### 4.2 Equity markets

Equity markets have probably received the most attention in empirical applications of contagion tests in East Asian markets. A number of these applications have examined the effects of contagion during the period associated with the turmoil in the Hong Kong equity market in late October 1997, including Baig and Goldfajn (1999), Forbes and Rigobon (2002), Baur and Schulze (2005), Baur and Fry (2006), Bond, Dungey, and Fry (2006), and Dungey, Fry, González-Hermosillo, and Martin (2005b). Of these, Forbes and Rigobon (2002), Baur and Schulze (2005), and Bond, Dungey, and Fry (2006) focus on Hong Kong as the identified source of the potentially contagious shocks, whereas the others look more generally at contagion in the region. Kleimeier, Lehnert, and Verschoor (2003) and Baur and Schulze (2005) focus on Thailand as the source country for the potentially contagious equity market shock.

Studies are divided in their results on the importance of contagion effects in Asian equity markets. On the one hand, Forbes and Rigobon (2002) and Kleimeier, Lehnert, and Verschoor (2003) find little or no evidence of contagion using tests based on a statistically significant increase in the correlation coefficient between returns in these markets. Both papers use the same methodology, although Kleimeier, Lehnert, and Verschoor control precisely for the timing of the observations on the various equity markets, whereas other studies use market-closing observations, resulting in differences in the effective times across the day. On the other hand, a num-

ber of papers do find significant contagion effects in East Asia. Caporale, Cipollini, and Spagnolo (2005) find evidence for contagion in almost all pairs of eight Asian economies using conditional correlation analysis.<sup>4</sup>

Bond, Dungey, and Fry (2006) show that during the period of 1997–98 associated with turmoil in Hong Kong, equity and real estate markets behave somewhat differently, but both indicate statistically significant contagion effects. This paper also emphasizes the role of the Japanese and Singaporean markets in helping to transmit the contagion effects around the region. Contagion from Hong Kong is found to be significant to Singapore and the Philippines by Corsetti, Pericoli, and Sbracia (2001) and from Hong Kong to a wide range of Asian economies by Baur and Schulze (2005). Baur and Fry (2006) find that contagion is significant across 11 countries during 8 percent of days over the period of the Asian crisis, with Hong Kong being an important factor.<sup>5</sup>

Bekaert, Harvey, and Ng (2005) and Wongswan (2003) also find evidence of significant contagion effects within Asia, but not from Asia to other countries or regions. Wongswan (2003) controls for common effects by fitting a capital asset pricing model, including GARCH conditional variances, and examines the correlations among the residuals across countries and regions. Baig and Goldfajn (1999) uncover mixed evidence of contagion in equity markets. They find evidence for bivariate contagion between Korea and each of Indonesia, Malaysia, the Philippines, and Thailand and between Indonesia and Malaysia and Indonesia and Thailand, but not between other pairings of these countries. There is also evidence of contagion from both Korean and Thai equity markets to Indonesian equities in Cerra and Saxena (2002), which uses a Markov switching modeling approach.

The effect of a change in the propagation of the common factor during the Asian crisis as an alternative explanation is explored in Rigobon (2003) using his determinant of change in covariance (DCC) test. The test does not suggest any break in the propagation in Asia during the Asian crisis but provides some limited evidence that other countries experienced a change in their propagation coefficients associated with the crisis in Thailand during 1997–98, notably India, South Africa, and Russia. Other evidence on structural breaks by Yang, Kolari, and Min (2003) suggests that

4 The countries considered are Hong Kong, Indonesia, Korea, Malaysia, the Philippines, Singapore, Taiwan, and Thailand.

5 The countries considered are China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, the Philippines, Singapore, Taiwan, and Thailand.

there was some increase in the intensity of the integration among the Asian equity markets during the crisis period.

### 4.3 Fixed-income markets

Studies of contagion in fixed-income markets for Asia are far less common than for other asset types. This partly arises from the relative stability in these markets up until the events of August–September 1998, when the Russian government suspended payment and subsequently defaulted on sovereign bond payments, creating substantial volatility in international bond markets; see the analysis of the period in the BIS report by the Committee on the Global Financial System (1999).

Only three studies have given particular attention to bond markets with East Asian markets as the focus. Baig and Goldfajn (1999) conduct a correlation analysis for bond spreads similar to that for the currency and equity markets and find evidence of contagion among the Asian sovereign bond markets. Debelle and Ellis (2005) consider links from East Asia to Australia and New Zealand through bond markets and find evidence of significant but small contagion effects. Sander and Kleimeier (2003) view contagion as a change in cross-market interdependencies, which they assess using Granger causality tests during pre-crisis and crisis periods. They find evidence for crisis-related changes in the short-term propagation mechanism, which they denote as contagion, namely, from the Philippines to Malaysia and Korea; from Indonesia to the Philippines, Thailand, and Malaysia; from Malaysia to Thailand; and from Korea to Indonesia. They attribute their finding of no contagion from Thailand as suggesting that Korea was a more important influence. However, this may well relate to the fact that the crisis in Thailand erupted in currency and equity markets and was not particularly visible in sovereign debt markets.

### 4.4 Cross-country linkages and cross-market linkages

In some cases, a particular asset market is hit by an identifiable shock, but this does not result in unusual levels of volatility in the returns for the asset. The clearest example of this phenomenon is the successful defense of managed or fixed-exchange-rate arrangements, such as those conducted by the currency board in Hong Kong over a number of instances in 1997–98. However, it would be incorrect to conclude that it is possible to isolate economies from the effects of such shocks, as the volatility was transferred to alternative asset types. In October 1997 and January, June, and August 1998, speculators attacked the Hong Kong currency board. In each case, the currency was successfully defended, but substantial volatility emerged in equity markets.<sup>6</sup> The general principle is that financial markets are closely interrelated and

<sup>6</sup> See Goodhart and Dai (2003) for a detailed review of the Hong Kong Monetary Authority's subsequent defense of its currency through equity market intervention.

that studying the transmission in crises across one asset market type in isolation may not yield the appropriate conclusions, particularly for policymakers who need to consider the impact on all asset markets and the economy in general.<sup>7</sup>

Given the well-known linkages between markets and economies in Asia, it is somewhat surprising that contagion in multiple markets has tended to be understudied. One possible reason is the obvious difficulties in combining models of the different markets. However, there are some developments in this vein of the literature. A few papers consider modeling linkages among different asset classes during a crisis within a particular country: Granger, Huang, and Yang (2000), Fang and Miller (2002), Hartmann, Straetmans, and de Vries (2004), and recently, for pairs of asset types across geographical borders, Hartmann, Straetmans, and de Vries (2004). Bond, Dungey, and Fry (2006) attempt to differentiate transmissions among real estate market instruments from those in the related equity markets by using orthogonal shocks obtained from regressing equity market returns on real estate returns. Some papers consider different asset types during the same crisis, but not the potential interactions among them; Baig and Goldfajn (1999) and Debelle and Ellis (2005) consider a range of markets during the Asian crisis of 1997–98.

More relevant to the current discussion are models that consider transmissions among multiple markets across potentially different asset types and a number of economies. Ito and Hashimoto (2005) use a Tobit model on extreme returns to test for contagion across equity markets and currency markets during the Asian crisis of 1997–98. Khalid and Kawai (2003) conduct Granger causality tests on the residuals of a VAR across equity, currency, and bond markets. Kaminsky and Reinhart (2002) identify the commonalities in equity, bond, and currency markets across a range of countries using principal-components methods.

These papers almost always find evidence of statistically significant contagion across different asset market types. Dungey and Martin (2006) find that equity market shocks are contagiously transmitted to currency markets and vice versa. This is supported by the Granger causality tests in Granger, Huang, and Yang (2000), which finds feedback between equity and currency markets for Malaysia, Singapore, Thailand, and Taiwan during the period of 1 June 1997 to 16 June 1998.<sup>8</sup> The exception to the finding of cross-market, cross-country linkages is Khalid and Kawai (2003), which concludes that the evidence for significant contagion is limited.

<sup>7</sup> The seminal work on crises by Kindelberger (1996) discusses the importance of cross-market financial interlinkages well before the Asian crisis.

<sup>8</sup> For other countries in the study, they find Granger causality from equity to currency markets for Hong Kong and the Philippines and from currency to equity markets for Korea.

A further important conclusion to be drawn from comparing both cross-market and cross-country evidence is that crises seem to propagate through various asset classes differently. This is shown to be the case for equity markets and currency markets in Dungey and Martin (2006), for equity markets and real estate instruments in Bond, Dungey, and Fry (2006), and for equity and bonds in Hartmann, Straetmans, and de Vries (2004).

## 5. Propositions and evidence

This section addresses, in turn, the seven propositions in regard to contagion outlined in the introduction. These propositions are investigated by drawing on nine papers of the authors, using versions of the factor decomposition approach. An advantage of this approach is that it is possible to decompose volatility into a set of latent factors, including a common factor, an idiosyncratic factor, and contagion factors, and thereby quantify the magnitude of contagion as a proportion of overall volatility. Other specifications include some combination of regional factors, asymmetric contagion factors to account for positive or negative contagion effects, multiple-asset markets, subperiods of contagion within a crisis, and in some applications, the simultaneous modeling of multiple crises. This factor structure is related to the model in equations (1) to (14) of Section 3. These papers are summarized in Table 1 in terms of the crisis addressed, the asset market investigated, the sample of countries considered, and the factor structure specified in the paper.<sup>9</sup>

### 5.1 Strong fundamentals imply immunity to contagion

Sachs, Tornell, and Velasco (1996) suggest that countries with strong fundamentals experience less contagion than other countries. Athukorala and Warr (2002) go further by saying that contagion cannot occur in countries that do not have some underlying “vulnerability,” in terms of some fundamental weakness; see also Kaminsky and Reinhart (1999). The evidence for Asia is mixed in this respect. Furman and Stiglitz (1998) suggest that the standard macroeconomic fundamentals in the main crisis countries showed little evidence of weakness ahead of the crisis. In contrast, Athukorala and Warr (2002) examine the financial fragility, reserve adequacy, and real exchange rate misalignment of the key crisis countries in comparison to a set of noncrisis countries and find the opposite result. Using the method of Frankel and Rose (1996), Furman and Stiglitz (1998) predict a less than 7 percent probability of a currency crisis in 1997 for Malaysia, Indonesia, Thailand, and the

<sup>9</sup> For precise information on the estimation of each model, consult the papers in Table 1. Model identification and estimation is discussed in general terms for both the tranquil period and the crisis period in section 3.1.

Table 1. Summary of papers on contagion by authors using factor models

Paper <sup>a</sup>	Crisis	Market	Countries	Factors
Dungey, Fry, González-Hermosillo, and Martin (2002)	Russia/LTCM	Bond	I,K,T,B,P,Ar,Br,Me,N,UK,US	Com, idio, reg, cont
Dungey, Fry, and Martin (2003)	Asia	Equity	A,HK,I,K,M,T	Com, idio, cont
Dungey and Martin (2004)	Asia	Currency	I,K,M,T	Com, idio, cont
Dungey, Fry, and Martin (2004)	Asia	Currency	I,K,M,T,A,J,NZ	Com, num, idio, reg, cont
Bond, Dungey, and Fry (2006)	Asia	Real estate and equity	A,HK,S,I,US	Com, idio, cont
Dungey and Martin (2006)	Asia	Equity/currency modeled jointly	A,K,J,M,T,US	Com, idio, mkt, enty, cont
Dungey, Fry, González-Hermosillo, and Martin (2005b)	1. Asia	Equity	1. HK,K,M	Com, idio, cont
	2. Tequila	Equity	2. Ar,C,Me	Com, idio, cont
	3. Argentine	Equity	3. Ar,Br,C	Com, idio, cont
Dungey, Fry, González-Hermosillo, and Martin (2005c)	Russia/LTCM	Equity	Ar,Br,HK,T,P,DM,I,UK,US	Com, idio, reg, cont
Dungey, Fry, González-Hermosillo, and Martin (2006a)	Russia/LTCM	Bond	I,K,T,B,P,Ar,Br,Me,N,UK,US	Com, idio, reg, cont

Note: A = Australia, Ar = Argentina, B = Bulgaria, Br = Brazil, C = Chile, DM = Germany, HK = Hong Kong, I = Indonesia, J = Japan, K = Korea, M = Malaysia, Me = Mexico, N = Netherlands, NZ = New Zealand, P = Poland, R = Russia, S = Singapore, T = Thailand, UK = United Kingdom, US = United States, com = common, idio = idiosyncratic, cont = contagion, reg = regional, mkt = market, enty = country, num = numeraire; LTCM = long-term capital management.

Philippines. In contrast 17 other countries are found to have higher probabilities of crisis.

The focus of existing studies has been on whether fundamentals in Asia were strong or weak relative to those in other countries that have experienced financial crises, as in the comparisons with the Mexican peso crisis presented in Sachs, Tornell, and Velasco (1996), Furman and Stiglitz (1998), and Kaminsky and Reinhart (1999). However, there may also be insights to be gained by comparing the relative strength of fundamentals within the crisis-affected countries in conjunction with the degree of contagion they experienced. The top panel of Table 2 provides details on the relative values of a selection of fundamental macroeconomic variables for Indonesia, Korea, Malaysia, and Thailand. These variables reflect those found to be important in the financial crisis literature represented by Sachs, Tornell, and Velasco (1996), Furman and Stiglitz (1998), and Frankel and Rose (1996).

A good set of economic fundamentals in Table 2 would be composed of a high GDP per capita, strong GDP growth, a low short-term-debt-to-reserves ratio, low and stable inflation, a low rate of nonperforming loans, and an exchange rate near its equilibrium value.<sup>10</sup> More difficult to interpret is the role of openness and export growth. Typically, openness is seen as a requirement for development, and a high degree of openness is desirable. Export growth is also generally seen as important to an economy, indicating strong domestic growth, although it may also be associated with overheating as in the case of Thailand; see Athukorala and Suphachalasai (2004).

The country with the strongest fundamentals in Table 2 is Korea. It has higher GDP per capita and higher average GDP growth in the run-up to the crisis, a low rate of nonperforming loans, and an exchange rate close to equilibrium. However, it also has the highest short-term-debt-to-reserves ratio of the four countries. Its openness and export growth are only slightly higher than those of Indonesia, which is clearly the worst-performing country in the sample on the basis of these indicators. Note that Kenward (1999) describes the lack of macroeconomic indicators of weakness in

10 The real exchange rate misalignment in Table 2 is computed relative to an equilibrium measure based on the predicted value of the real exchange rate in 1996 estimated with levels of real GDP per capita taking into account the Balassa-Samuelson effect. Furman and Stiglitz (1998) give four alternate measures, of which this is one, and the extent (and even sign) of the deviation from equilibrium differs across the measures. Two of the measures given in Furman and Stiglitz agree with the relative ordering of the extent of misalignment here, that is, that Malaysia is the most misaligned and Korea the least. The other two measures suggest that Korea is the most misaligned and Indonesia the least. Hence, the results vary enormously with the measure chosen, and undue weight should not be placed on the indicator adopted in Table 2.



Table 2. Fundamental indicators and extent of contagion experienced by country

	Indonesia	Korea	Malaysia	Thailand
<b>Fundamentals</b>				
GDP per capita, 1997 (US\$) <sup>a</sup>	4,137	14,704	9,689	7,051
Average GDP growth (%), 1970-96 <sup>a</sup>	5.06	6.63	4.54	5.49
Short-term-debt-to-reserves ratio, June 1997 <sup>b</sup>	1.7	2.07	0.61	1.45
Consumer price inflation (%), 1997 <sup>c</sup>	4.67	4.37	1.01	4.37
Nonperforming loans (% of total), 1996 <sup>d</sup>	8.8	0.8	3	n.a.
Openness <sup>a</sup> (X + M)/Y	56.04	67.63	178.26	84.16
Export growth, 1986-96 (%) <sup>e</sup>	236	274	471	528
Exchange rate overvaluation, 1996 (%) <sup>f</sup>	-16	1	-41	-18
Moody's ratings <sup>g</sup>	Baa3	A1	A1	A3
Standard and Poor's rating <sup>h</sup>	BBB	AA-	AA+	A
<b>Financial links</b>				
Net capital flows, 1996 (US\$ million) <sup>i</sup>	9,841	14,535	13,824	10,487
U.S. direct investment, 1996 (US\$ million) <sup>j</sup>	956	752	1,298	849
Net FDI flows, 1996 (US\$ million) <sup>j</sup>	5,594	-2,345	7,927	1,404
<b>Extent of volatility due to contagion</b>				
	Contagion proportion of volatility (%)			
<b>Market</b>	<b>Indonesia</b>	<b>Korea</b>	<b>Malaysia</b>	<b>Thailand</b>
<b>Currency market</b>				
Dungey and Martin (2004)	19.75	46.31	9.59	29.14
<b>Equity market</b>				
Dungey, Fry, González-Hermosillo, and Martin (2005b)		74.45	49.92	
Dungey, Fry, González-Hermosillo, and Martin (2005c)		10.11	22.65	11.00
<b>Bond market</b>				
Dungey, Fry, González-Hermosillo, and Martin (2006a)	0.68	5.32		7.78

Sources: a. Penn World Tables v 6.1 accessed via NBER website; b. Radelet and Sachs (1998), Table 3; c. IMF IFS statistics, authors' calculations; average monthly annual inflation rate for January-June 1997; Datanstream series identifier XX64... F, where XX is the appropriate country abbreviation; d. Radelet and Sachs (1998), Table 10; e. IMF IFS statistics, authors' calculations; Datanstream series identifier XXI70... DA, where XX is the appropriate country abbreviation; f. Furman and Stiglitz (1998), Table 2; column 3 per capita GDP adjusted; g. Moody's sovereign rating foreign currency country ceiling for bonds and notes prior to crisis; h. Standard and Poor's foreign currency sovereign credit rating prior to crisis; i. Athukorala (2003), Tables 1 and 4. Note: n.a. = not available.

Indonesia prior to the crisis, and Iriana and Sjöholm (2002) find less evidence of weakness in Indonesia than in other economies in the region but point to the role of the larger share of short-term debts. Table 2 shows that Indonesia has the least-favorable GDP per capita, ratio of nonperforming loans, openness, and export growth criteria. Thailand stands out in the sample of data here only in terms of its high export growth.

The Malaysian experience places it as the strongest among the four countries in terms of inflation, short-term-debt-to-reserves ratio, and openness. However, it also features substantial exchange rate misalignment and lower GDP growth than the other countries. From this particular selection of economic indicators the relative economic strength of these economies looks to favor Korea as the strongest, Indonesia as the weakest, and Malaysia as stronger than Thailand. Although the economic indicators selected here are not exhaustive, they are indicative of those in use in the financial crisis literature.

With this broad ranking in mind, the contributions of contagion to observed volatility in currency, equity returns, and sovereign debt spreads over U.S. Treasuries can be assessed. The lower panel of Table 2 presents evidence of the proportion of observed volatility due to contagion while controlling for fundamentals from a number of the studies carried out by the present authors. The currency market study in Dungey and Martin (2004) is most informative as it includes all the countries considered in Table 2.

Korea experiences the greatest contribution to currency market volatility from contagion (46.31 percent), despite its relatively stronger fundamental position revealed in the first panel of Table 2. Malaysia, however, which is arguably also relatively well-positioned fundamentally, displays the lowest contribution of contagion at 9.59 percent in this market. In the equity market study of Dungey, Fry, González-Hermosillo, and Martin (2005b), contagion effects from Hong Kong are a greater proportion of volatility in Korea (74.45 percent) than Malaysia (49.92 percent), suggesting that Korea had more vulnerability to contagion than Malaysia. In contrast, contagion effects from Korea to Malaysia were a greater part of Malaysian volatility (22.65 percent) than were contagion effects from Malaysia to Korea on Korean volatility (10.11 percent). Hence, the evidence is somewhat mixed as to whether Malaysia or Korea experienced greater contagion effects in the equity markets.

In bond markets, Thailand experienced the largest contagion effects from the Russian collapse and LTCM crisis in August 1998 (7.78 percent), while Indonesia experienced little. The small extent of contagion to Indonesia suggests that perhaps after

its own crisis it developed immunity, at least for a period, to contagion from further crises; see also Dungey, Fry, González-Hermosillo, and Martin (2006a).

The combination of the evidence on market fundamentals and the extent of contagion effects identified provide a mixed picture. While the more general literature on crises may have drawn the conclusion that poor fundamentals are associated with more contagion effects, this is hard to discern in comparing the relative performance of these economies with this set of economic indicators.

## 5.2 Trade and financial linkages are important

Trade links are regarded as primary mechanisms for contagion in Glick and Rose (1999). Van Rijckeghem and Weder (2001) find that financial effects through common lenders are a more important route of transmission, although trade links may still be important. A difficulty arises in differentiating trade and financial links if the two effects are highly correlated, as Van Rijckeghem and Weder demonstrate is the case for Asia. Athukorala and Warr (2002) argue that trade links cannot be a mechanism of propagation in Asia, as bilateral trade flows are relatively small among Asian countries. But this overlooks the trade-related effects of competitive devaluation due to export competition, which is argued as a primary driver of the spread of the Asian crisis by Goldstein (1998). Baig and Goldfajn (1999) find little evidence for either trade or competitive devaluation, while De Gregorio and Valdés (2001) provide empirical evidence that the regional nature of crises and contagion is largely unrelated to trade links. Karolyi (2003) argues that the focus on trade is misplaced as contagion reflects rational behavior on the basis of liquidity (those with the most liquid markets may suffer more).

Indicators of financial fragility explored in the existing literature include net investment flows, domestic financial liberalization, and banking linkages; see, for example, Wyplosz (2001), Van Rijckeghem and Weder (2001, 2003), and Furman and Stiglitz (1998), *inter alia*. A number of indicators of the financial position of four East Asian economies are given in the middle panel of Table 2. The choice of these indicators is again drawn from the relevant literature on financial crises. As with the indicators in regard to fundamentals, there is not a clear relationship between the financial linkages positions of the four countries and the extent of contagion experienced by each.

While the empirical papers of the current authors canvassed here do not provide direct evidence on the importance of trade and financial linkages, there are some observations that can be drawn out. In the investigations of the Russian and LTCM crises in Dungey, Fry, González-Hermosillo, and Martin (2005c, 2006a), some of the

strongest contagion effects from Russia are felt by countries with strong financial linkages with Russia. Consistent with the evidence of Van Rijckeghem and Weder (2001, 2003), Kaminsky and Reinhart (1999), and Pritsker (2001), the banking exposure of the Netherlands and Germany to Russia seems consistent with the relatively large contributions of contagion to volatility in their financial markets compared with other developed markets in the period. On the trade side, it was widely expected that the Asian crisis would affect the Australian and New Zealand economies given their strong trade linkages; see Summers (2001) for Australian evidence. In the event, however, the contagion effects documented in Dungey, Fry, and Martin (2003, 2004) to the Antipodes are quite small. This small amount of evidence suggests that perhaps trade links are a less important prerequisite for contagion than are financial linkages in the region.

### 5.3 Regional proximity is important

A common observation is that crises and contagion pertain to geographically clustered regions with little spillover to other countries. This proposition is intrinsically related to the hypothesis that trade linkages, which are often between geographically proximate nations, are important for contagion and may also arise as a result of portfolio-balancing arguments as well as similarity of fundamentals. The validity of this proposition is examined by considering the importance of contagion within regions and the importance of contagion across regions. Although the analysis of the regional nature of contagion through the empirical work presented here is limited in that regions that did not suffer during the crises are generally, but not always, omitted from the sample, there are several instances in which cross-regional linkages are modeled.

Table 3 summarizes the proportion of observed asset market volatility due to contagion across various papers relating to the Asian financial crisis. It shows that within the Asian region there is a lot of contagion during the Asian financial crisis. In particular, contagious linkages in currency markets are strong from Thailand to Korea and Malaysia, with the contribution of contagion to volatility of currency markets in Korea and Malaysia greater than 28 percent. Contagion in equity and real estate markets during the Asian crisis is always strong from Hong Kong to the other Asian economies. Evidence from other crises in Dungey, Fry, González-Hermosillo, and Martin (2005c, 2006a) shows that during the Russian crisis, contagion from Russia to Eastern Europe (Poland) is strong in equity markets, but less so in bond markets (Bulgaria and Poland), which is probably related to thin bond markets in the even-les-developed Eastern European economies. Similarly, contagion during the U.S.-based LTCM crisis transmits strongly to Latin America in equity markets, but not in bond markets.

**Table 3. Percentage contribution of contagion to the volatility of various asset markets during the Asian crisis**

Paper	Contagion to	Contagion from								
		Asia <sup>a</sup>	HK	I	K	M	T	J	S	US
<b>Equity markets</b>										
Dungey, Fry, and Martin (2003)	Australia		0.59	0.9	0.24	0.67	5.6			
Bond, Dungey, and Fry (2006) <sup>b</sup>	Australia		33–65					1–12	16–30	<0.5
	HK							3–20	2–70	1–19
	Japan		23–40						7–36	0.6–18
	Singapore		10–74					2–70		<0.5
	US		<0.5					1–19		
Dungey, Fry, González-Hermosillo, and Martin (2005b)	Hong Kong				74.45	49.92				
	Korea		60.51			22.65				
	Malaysia		18.1		10.11					
<b>Currency markets</b>										
Dungey and Martin (2004)	Indonesia				6.2	13.1	0.45			
	Korea			5.3		10	31			
	Malaysia			0.5	0.2		28.5			
	Thailand			0.6	4.5	4.5				
Dungey, Fry, and Martin (2004)	Australia	1.7								
	Japan	0.13								
	New Zealand	3.1								
<b>Real estate markets</b>										
Bond, Dungey, and Fry (2006)	Australia	39–67						7–20	13–71	<0.5
	Hong Kong							0.5–14	44–88	<0.5
	Japan	7–21							16–17	0.01–3.6
	Singapore	4–38						28–57		<0.5
	US	<0.5						7–38		

*Notes:* HK = Hong Kong, I = Indonesia, K = Korea, M = Malaysia, T = Thailand, J = Japan, S = Singapore, US = United States.

a. Asia: joint contagion from Indonesia, Korea, Malaysia, and Thailand.

b. The range represents results from two separate periods of turmoil in Hong Kong equity markets.

Dungey, Fry, and Martin (2003, 2004) and Bond, Dungey, and Fry (2006) analyze contagion from Asia to asset markets in Australia, Japan, and New Zealand. There is no systematic contagion to any of these countries from the key crisis countries, although there is substantial contagion in equity and real estate markets from the developed regional countries of Hong Kong, Singapore, and Japan to Australia, and from Australia, Hong Kong, and Singapore to Japan. Debelle and Ellis (2005) also find little evidence of contagion to Australia from the Asian crisis. The roles of developed markets in the crisis are discussed in sections 5.4 and 5.5.

Dungey, Fry, González-Hermosillo, and Martin (2005c, 2006a) model contagion in bond and equity markets in the Russian and LTCM crises across and within regions, with the result that there is cross-regional equity market contagion from both Russia (17 percent) and the United States (14 percent) to Hong Kong, and from Russia to Brazil (16 percent) in bond markets. During this period Hong Kong was experiencing its own financial turmoil associated with another speculative attack on its currency board, which was successfully defended by intervention in equity markets

(Goodhart and Dai 2003), and Brazil was to experience its own crisis in early 1999. Baig and Goldfajn (2001) discuss the transmission of the Russian crisis to Brazil.

To clarify further the evidence presented from the latent-factor models, Table 4 collates the percentage of total contagious linkages which are classified as small (less than 5 percent of total volatility), moderate (between 5 and 30 percent of total volatility), and strong (more than 30 percent of total volatility) within and across regions as evident in the selected papers. The table shows that 66 percent of all linkages within a region across the papers are deemed to be either moderate or strong. If linkages due to the United States, which may be considered to be systemic, are excluded, the number is still substantial, with 59 percent of linkages considered to be moderate or strong. Of the cross-regional linkages, 54 percent are regarded as minimal, with the remainder considered moderate once the United States is excluded.

Several other studies support the hypothesis that crises are regional. Yang, Kolari, and Min (2003) examine the integration of Asian equity markets during the crisis. They find that the key crisis countries are more integrated during the crisis period and are also more responsive to external shocks. Goldstein (1998), Kaminsky and Reinhart (2000), Glick and Rose (1999), and Gerlach and Smets (1995) all emphasize the importance of regional effects in the transmission of crises.

#### **5.4 Emerging markets experience more contagion than developed markets**

Generally, financial crises are thought to be the domain of emerging markets. However, sometimes crises occur “mysteriously on a worldwide basis” (Wyplosz 2001, 9); that is, they are systemic. The Committee on the Global Finance System (1999) claims that the Russian crisis affected only emerging markets, while the LTCM crisis affected developed markets. A similar conclusion is put forward by Bae, Karolyi, and Stulz (2003), who find that for a range of international equity markets, emerging markets are more susceptible to international financial crises than developed markets. Clear examples of developed countries affected by crises are Korea, which is a member of the OECD, and Hong Kong, which has one of the most liberalized financial systems in the world. Potential linkages that exist between the markets of developed and emerging nations include increasing globalization, trade linkages, foreign direct investment (particularly through the direct investment of financial intermediaries), and portfolio investment decisions of investors who seek to diversify their portfolios by investing in emerging markets.

The proposition that emerging markets experience more contagion than developed markets is also difficult to disentangle from the proposition that strong fundamentals mean immunity to contagion. In general, developed markets have stronger fun-

**Table 4. Percentage of important contagious linkages within and across regions as evident in selected papers**

Percentage of volatility	Level of Contagion		
	Minimal < 5%	Moderate 5–30%	Strong > 30%
<b>Contagion within regions</b>			
All regional linkages	34	39	27
Regional linkages excluding U.S.	27	35	24
Regional linkages excluding U.S. and Australia	38	39	23
<b>Contagion across regions</b>			
All cross-regional linkages	56	32	12
Cross-regional linkages excluding U.S.	54	46	0

*Note:* Papers are Dungey, Fry, and Martin (2003, 2004); Dungey and Martin (2004); Dungey, Fry, González-Hermosillo, and Martin (2005b, 2005c, 2006a); Bond, Dungey, and Fry (2006).

damentals than emerging economies. The evidence presented in Dungey, Fry, González-Hermosillo, and Martin (2002, 2005c, 2006a) does not support this proposition. The results are instead mixed and depend on how the impact of a crisis is measured. In the study of bond markets in the Russian and LTCM crises by Dungey, Fry, González-Hermosillo, and Martin (2006a), the proportion that contagion contributes to volatility in developed markets is equivalent to that in emerging markets. For the same crisis, the proportion of volatility in equity markets due to contagion from Russia is higher for developed markets than for emerging markets.

The proportions of volatility due to contagion can be transformed into a contagion levels effect by scaling the proportions in accordance with the observed volatility in the asset markets. Because of the overall higher level of volatility in emerging markets in general, the levels effect of contagion is generally smaller in developed markets than in emerging ones. This point is clearly demonstrated in Table 5, which presents the volatility decompositions of changes in bond market premia into common, country-specific, regional, and contagion factors for nine emerging and three developed countries. The volatility decompositions are presented in terms both of percentage contributions to volatility and of squared basis points. The volatility decomposition in percentage terms shows that the world factor contributes more than 80 percent to volatility in both types of countries. For the emerging countries, contagion contributes between 0.1 percent (in the case of Russia) and 16 percent (in the case of Brazil), while for the developed countries, the range is between 0.25 percent for the United Kingdom and 17 percent for the Netherlands. Even though in percentage terms contagion is of similar magnitude across the types of countries, the second panel of the table shows that 17 percent contagion to the Netherlands is equivalent to just 4.99 basis points squared, while 16 percent contagion to Brazil is equivalent to 585.6 squared basis points.

**Table 5. Comparison of contagion volatility decomposition of bond markets during the Russian crisis: Percentage and squared basis points**

Country	Common	Country-specific	Regional	Contagion
<b>Percentage decomposition</b>				
<b>Industrials</b>				
U.K.	99.74	0.01	n.a.	0.25
U.S.	84.97	11.83	n.a.	3.20
Netherlands	82.29	0.52	n.a.	17.19
<b>Eastern Europe</b>				
Bulgaria	91.33	0.20	0.52	7.95
Poland	93.71	0.05	0.66	5.59
Russia	94.73	5.06	0.11	0.10
<b>Asia</b>				
Indonesia	98.85	0.27	0.21	0.68
Korea	88.85	4.95	0.88	5.32
Thailand	90.52	1.32	0.38	7.78
<b>Latin America</b>				
Argentina	86.83	12.68	0.05	0.45
Brazil	83.15	0.18	0.01	16.66
Mexico	99.74	0	0.01	0.26
<b>Squared basis points decomposition</b>				
<b>Industrials</b>				
U.K.	13.88	0	n.a.	0.04
U.S.	6.38	0.89	n.a.	0.24
Netherlands	23.91	0.15	n.a.	4.99
<b>Eastern Europe</b>				
Bulgaria	9,138.09	20.38	51.62	795.11
Poland	494.42	0.25	3.48	29.48
Russia	55,685.89	2,973.20	62.97	59.94
<b>Asia</b>				
Indonesia	3,085.45	8.39	6.41	21.21
Korea	728.81	40.60	7.22	43.62
Thailand	452.58	6.59	1.88	38.92
<b>Latin America</b>				
Argentina	984.34	143.71	0.51	5.12
Brazil	2,923.10	6.47	0.14	585.60
Mexico	525.31	0.01	0.03	1.35

Note: n.a. = not applicable.

This is not quite the same as saying that emerging markets experience more contagion than developed markets. Although clearly the absolute level of contagion experienced does matter for a country's policymakers, it is not as clear whether policymakers should be concerned about the proportionate or the absolute contribution of contagion.

### 5.5 Developed financial markets can transmit contagion among regions

The hypothesis that developed markets are a conduit for financial contagion among emerging markets, as suggested in Frankel and Schmukler (1996) and Kaminsky and Reinhart (2003), is consistent with the evidence reported in the papers listed in Table 1. Support for this proposition is highlighted by comparing Dungey, Fry, and Martin (2003) and Bond, Dungey, and Fry (2006), who study the impact of contagion



during the Asian crisis on Australian equity markets. Dungey, Fry, and Martin (2003) examine contagion from the countries traditionally considered crisis countries, including Hong Kong, Indonesia, Korea, Malaysia and Thailand, while Bond, Dungey, and Fry (2006) focus on the more-developed countries of the Asian region during the same crises, including Japan, Singapore, Hong Kong, and the United States. Dungey, Fry, and Martin (2003) find little evidence of contagion to Australia from the traditional crisis countries, while there is much more evidence of contagion to Australia from the more-developed Asian economies and the United States, particularly from Hong Kong, Singapore, and Japan. Both Singapore and Japan seem to play a key role in transmitting contagion among the countries within the Asian region. Further supporting evidence can be found in Dungey and Martin (2004, 2006), in which the majority of the effects transmitted to Australia tend to come through the U.S. market.

Contagion may also be reinforced by transmissions from other emerging countries involved in the crisis. In many of the studies examined, two or more countries show substantial contemporaneous contagion links. For example, in the Dungey, Fry, González-Hermosillo, and Martin (2005b) application of equity markets during the collapse of the Hong Kong equity market, there is strong contagion to Malaysia originating in Hong Kong and strong contagion to Hong Kong originating in Malaysia. The inclusion of developed markets in estimating the effects of contagion helps to provide a clearer picture of the propagation mechanisms.

### 5.6 Contagion effects differ by asset market

While the characteristics of alternative asset markets are known, it also seems that different asset markets have different vulnerabilities to contagion effects. In general, the variation in returns attributable to contagion is relatively smaller in currency markets and relatively larger in equity markets. It is harder to characterize bond markets given the smaller body of research. Dungey, Fry, González-Hermosillo, and Martin (2005c, 2006a) investigate the same crises (Russia and LTCM) for both bond and equity markets, with the result that the proportion of volatility due to contagion in the bond markets is relatively much smaller. The evidence suggests that among countries actually involved in a financial crisis, as opposed to those on the periphery, contagion is largest in equity markets and smallest in bond markets, with currency markets in between.<sup>11</sup> This generalization seems to stand regardless of the asset market in which the initial shock occurs. In the Russian/LTCM crisis of 1998, which is broadly considered to have originated in the Russian bond market, the

<sup>11</sup> Kaminsky and Schmukler (1999) find volatility in U.S.-dollar-denominated stock returns during the Asian crisis to be predominantly equity market related, with the notable exception of Indonesia.

bond market shows less contagion than corresponding equity markets.<sup>12</sup> A comparison of equity and currency markets in the Asian crisis shows stronger contagion effects in equities: compare Dungey, Fry, and Martin (2004) for currency markets with Dungey, Fry, and Martin (2003) for equity markets.

### 5.7 Contagion occurs between different economies and different asset types

Models that capture linkages both across asset types and across international borders provide a clearer picture of a crisis; for a historical perspective see Kindelberger (1996). An important question for researchers and policymakers involves understanding how crises evolve. The examples discussed here suggest that single-asset-type investigations are far too restrictive. The implication is that there is limited scope for policy or infrastructure reform that concentrates on a single asset type. It is necessary to consider the interrelationships among all financial assets. This argument is analogous to the one against the implementation of Tobin taxes in currency markets, where such taxes simply encourage innovation into other markets. This suggests also that one potential source for aiding reform is the development of alternative financial derivatives; see Allen and Gale (2000).

The empirical results in Dungey and Martin (2006) and Bond, Dungey, and Fry (2006) support the importance of cross-asset market linkages. Dungey and Martin (2006) model contagious linkages between equity and currency markets across multiple countries in the Asian crisis. The results indicate that the contagion effects from currency markets account for up to 11 percent of equity market volatility, while contagion effects from equity markets account for up to 36 percent of volatility in currency markets. This proposition has an important implication for minimizing risk via portfolio diversification. The results clearly show that risk management should consider both cross-border diversification and cross-asset-type diversification. The traditional approach in the 1990s of segmenting asset types and managing the risks for each asset type separately is clearly not risk minimizing in a crisis period.

## 6. Conclusions: How important is contagion?

The empirical evidence and propositions presented above suggest that contagion exists and, to some extent, can be characterized as more likely to occur in emerging countries without clear regard to fundamentals. In general, contagion is regionally clustered and occurs among countries with strong financial linkages. In addition, contagion effects spread via developed financial markets, across both country bor-

<sup>12</sup> Although see Dungey, Goodhart, and Tambakis (2005) for the role of turmoil in Hong Kong equity and currency markets.

ders and asset types, and the nature of the spread of contagion differs by asset market. Having ascertained these characteristics, it is vital to examine just how important contagion effects are in comparison with myriad factors that may impact international and domestic financial markets.

The issue to be decided is whether domestic policies or international reforms are the more appropriate means of dealing with financial market contagion. If crises spread as a result of pure contagion, then perhaps there is merit in reform of international financial architecture. Glick and Rose (1999) argue that the regional nature of contagion associated with trade linkages suggests a role for international monitoring. Alternatively, if the main cause of asset market volatility during crises is factors associated with market, country-specific, or idiosyncratic factors, then the appropriate response is to pay more attention to national policies; see Karolyi (2003).

Finding the source of potentially contagious shocks is an additional complication. Based on the foregoing discussion, it is often not clear which asset markets are involved in the transmission of financial crises. In many crises, turmoil in one asset type seems to transmit to another. It can be difficult to identify the true trigger of a crisis, as for example in the ongoing debate as to whether the float of the Thai baht can be truly assigned as the beginning of the Asian crisis, as is done in many studies, or whether the crisis was detectable much earlier in equity markets.

The calculations on the contribution of contagion to observed crisis period volatility during various crises presented in Table 3 and other tables provide an indication of the importance of other factors in explaining volatility. The message of the results is that most of the observed volatility is not due to contagion. There are a number of exceptions to this, in which contagion effects exceed 50 percent of observed volatility. However, the general picture suggests that other factors, either singly or in combination, are more important. Khalid and Kawai (2003) find little evidence of contagion, and De Gregorio and Valdés (2001) support this result with their findings of the strong role of fundamentals in crises, compared with contagion effects. On the other hand, Cartapanis, Dropsy, and Mametz (2002) find that the role of contagion dominates that of fundamentals.

Contagion effects in currency markets seem to be uniformly small. Potentially, Karolyi (2003) is correct to single out exchange market reform as a cure for contagion as probably ineffective; see also the mixed results on the effectiveness of exchange rate flexibility in limiting contagion effects in De Gregorio and Valdés (2001). The fixed-income-markets example of Dungey, Fry, González-Hermosillo, and Martin (2006a) also suggests small contagion effects and that volatility reflects primarily

other factors. Equity markets experience the most contagion effects, yet there are no analyses considering reform to equity markets to limit such effects.

The extent of interest in international reform and the measure of contagion effects seems to be in inverse proportion in the literature: the most attention has been paid to reform of currency markets, where the contagion effects are limited, and the least attention to reform of equity markets, where substantial contagion effects are more evident.

The different asset markets have different contributors to volatility in crisis periods, and crises spread both across asset markets and across countries. This implies that there is no one solution for handling a particular crisis, as responses will depend on the source shock(s) and the propagation mechanism. While it is known that financial crises are costly (Bordo, Eichengreen, Klingebiel, and Martinez-Peria 2001), it may be that avoiding financial crises is costly in terms of lost economic opportunities as well. Assessing these relative costs is an extremely difficult task, but it is one on which the decisions of international and national policymakers should focus in attempting to develop solutions to reduce financial contagion and crises. Some of these issues may be about the distribution of costs rather than their reduction to zero.

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