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RESEARCH ARTICLE

Contagion and Global Financial Crises: Lessons from Nine Crisis Episodes

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Abstract Episodes of extraordinary turbulence in global financial markets are examined during nine crises ranging from the Asian crisis in 1997–98 to the recent European debt crisis of 2010–13. After dating each crisis using a regime switching model, the analysis focuses on changes in the dependence structures of equity markets through correlation, coskewness and covolatility to address a range of hypotheses regarding contagion transmission. The results show that the great recession is a true global financial crisis. Finance linkages are more likely to result in crisis transmission than trade and emerging market crises transmit unexpectedly, particularly to developed markets.

Keywords Contagion testing · Correlation · Coskewness · Covolatility · Asian crisis · Russian crisis · LTCM crisis · Brazil crisis · Dot-com crisis · Argentinian crisis · Sub-prime crisis · Great recession · European debt crisis · Global financial crisis

JEL Classifications C11 · C34 · C51 · G15

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1 Introduction

This paper provides evidence on the nature and existence of contagion during global financial crises by examining nine crisis episodes in equity markets, ranging from the Asian crisis to the European debt crisis. This paper is different to other approaches to modelling contagion, as it distinguishes between the dating of a crisis and the dating of contagion. A crisis occurs in a 'trigger' country which is the source of the financial turmoil, and the trigger is usually an extreme event.[1] Contagion is then the transmission of the crisis from the source to other markets through channels outside normal market linkages. Unlike most other papers in this area, contagion is allowed to vary as the crisis unfolds. This allows conclusions to be drawn on the evolution and duration of contagion on a variety of platforms. Uncovering these patterns means that policy makers can adjust concerns about contagion if it is a phenomenon that lasts for a short period of time compared to episodes of persistent duration.[2]

The sample of 27 equity markets is selected to capture different features of the global equity market, comparable with the Forbes and Rigobon (2002) dataset for 1987–1998. The data is presented in Fig. 1 from 1995 to 2013. The shaded areas highlight the crisis episodes and show the dramatic market collapses and associated volatility when a crisis is triggered. The figure illustrates the connectedness of equity markets as they fall simultaneously. In terms of the features of markets, the sample consists of a range of emerging markets, OECD markets, markets that are the source of the crisis and others that are not directly a crisis country. The crises themselves originate in diverse regions, with five sourced in developed markets and four in emerging markets. Examining the multi-crisis, multi-country dataset allows evaluation of a range of hypotheses about contagion. These include an assessment of which crises are true global financial crises, and whether trade and finance links, regional proximity to the source market, or similar levels of development to the source market increase susceptibility to contagion.

The crisis dating is done using a regime switching model (Hamilton 1989) with the estimation taking into account our knowledge of trigger events. This method avoids the pitfalls inherent in using subjective methods to date periods of crisis for use in the analysis of contagion. Several papers use a regime switching model to distinguish bull and bear markets (Ang and Bekaert 2002), switching in correlation structures (Pelletier 2006; Billio and Caporin 2005; Kasch and Caporin 2013), time varying volatility (Gravelle et al. 2006), switching in higher order comoments (Chan et al. 2013), and Markovian switching with DCC GARCH features to examine market synchronization. This paper distinctly uses the crisis dates from the regime switching for the source market to then analyze contagion transmission to the other markets.

[1]For example, the collapse of Lehman Brothers marks the start of the great recession.

[2]During financial crises, countries worry that they will be affected in unexpected ways. For example, speculation during the Asian crisis in the US was that a recession was imminent and that American workers would lose their jobs (Galbraith 1998). The Russian and LTCM crisis was concluded to be the "worst crisis ever" (Committee on the Global Financial System 1999), and in the recent great recession it was expected that emerging countries would experience "sudden stops" (Blanchard 2008).

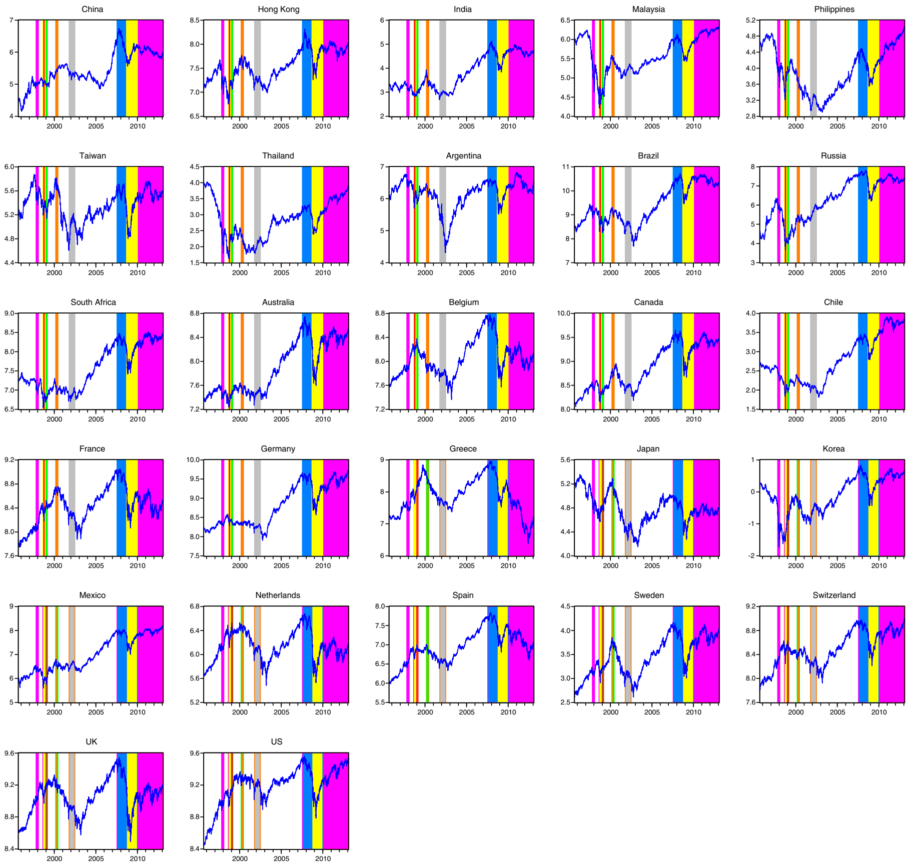

Fig. 1 Daily equity prices (natural logs) - September 1, 1995–January 31, 2013. The shaded areas refer to episodes of crisis in international equity markets. These are (i) the Asian financial crisis (October 20, 1997 to January 30, 1998); (ii and iii) the Russian bond default and the LTCM crisis (Russia: August 17, 1998 to December 31, 1998; LTCM: September 23, 1998 to October 15, 1998); (iv) the Brazilian crisis (January 7, 1999 to February 25, 1999), (v) the dot-com crisis (February 28, 2000 to June 7, 2000); (vi) the Argentinian crisis (October 11, 2001 to June 30, 2002); (vii) the sub-prime crisis (July 26, 2007 to September 14, 2008); (viii) the great recession (September 15, 2008 to December 31, 2009); and (ix) the European debt crisis (January 1, 2010 to January 31, 2013)

Once the crisis dates are known for the source country, four related contagion tests are then applied to detect shock transmissions to the recipient markets. These tests capture changes in various aspects of the asset return relationship during crises. The most obvious measure of market comovement is through correlation and the change in the correlation coefficient is an often used measure of contagion (Forbes and Rigobon 2002), but it is possible that there are non-linear channels requiring examination. In particular, volatility spillovers across markets are potentially important links as found in Diebold and Yilmaz (2009). The test statistics here are a correlation change test which tests for contagion between market asset returns, two versions of a coskewness change test which tests for contagion between average returns in one market and the volatility of returns of a second market and vice versa, and a new covolatilty change test which identifies contagion between market return volatilities (Forbes and Rigobon 2002; Fry et al. 2010; Hsiao 2012). Diebold and Yilmaz is the closest paper to ours. They construct indexes of return spillovers between markets, and volatility spillovers between markets, and find that volatility spillovers are particularly important during crisis periods. They do not examine spillovers between average returns and volatility as we do here. Other related papers include Beirne et al. (2009) which shows that contagion in developed markets can be the result of volatility in a developed crisis market.[3]

Although a direct mapping between the data and theoretical models is impossible given the limitations in data collection, different theoretical models predict the behavior in returns that the statistics are designed to capture, as many theoretical models imply asymmetric distributions or asymmetric dependence between markets during crises. Most of this asymmetry arises through investor behavior. For example, Harvey and Siddique (2000) and Fry et al. (2010) show that risk averse agents adjust their skewness and coskewness preferences during periods of risk and volatility; Yuan (2005) shows that borrowing constraints and information asymmetry change the distributions of asset returns; and Guidolin and Timmerman (2009) show the portfolio allocation implications of higher order comoments. The statistics used in this paper provide evidence on the multivariate implications of these theoretical concepts for changes in asset return dependence or contagion.

The results indicate that whilst contagion is most prevalent through the correlation and covolatility channels, all channels should still be examined. Overall, contagion is not significant on every day over the crisis period, but tends to appear in clusters at roughly the same time for groups of countries and is often short lived. The great recession and the European debt crisis are true global financial crises. In both crises all channels are in operation. The LTCM and dot-com crises are well accounted for by normal interdependencies. Contagion during crises sourced in emerging markets are consistently evident, and it is often the developed markets that are affected by emerging market crises. Trade and finance linkages do not necessarily accelerate changes in crisis transmission mechanisms, but the evidence indicates that strong financial linkages are more likely to be correlated with contagion transmission when compared to trade links, particularly during the great recession.

The rest of this paper proceeds as follows. Section 2 specifies the methods used to identify crises and contagion. Section 3 describes the crises and data used in this paper and then discusses the formal dating of crises and suggested triggers. Hypotheses surrounding features of the expected transmission of contagion and the methods for their evaluation are set out in Section 4. The results are presented in Section 5 with concluding comments given in Section 6.

[3]GARCH type models are another alternative method to that adopted here (Susmel and Engle 1994).

2 Identifying Crises and Contagion

This section sets out the method for dating each crisis in the asset market that is the ‘trigger’ or the source of the crisis. It then summarizes the tests for contagion that are used to analyze the transmission of contagion once the crisis dates are determined.

2.1 Crisis Dating Method

As contagion tests are conditioned on a ‘state’ of nature s_t, the dating of the crisis period is an essential component in understanding the transmission of a crisis from a source to a recipient asset market. Often there is no consensus to the dating of a particular crisis (Kose 2011) and the selection of crisis dates can influence the results in empirical testing. There is a body of work emerging where the dates of historical crises are defined but this applies mainly to banking crises which is not always applicable here. The dating is also not consistent across papers. See for examples Caprio et al. (2005), Laeven and Valencia (2008), Reinhart and Rogoff (2008b) and Reinhart (2010). A summary of papers written on one or more of the nine crises in equity markets considered here is compiled in Tables 9, 10, 11, 12 and 13 in Appendix C. The tables summarize the choice of crisis source market, non-crisis and crisis dating, data frequency and asset markets considered, and illustrate the disparity of the crisis dating choices in the contagion literature.

To date the crisis periods, this paper applies a regime switching model to the equity returns data for each market *(i)* assumed to be a source crisis market at some time during the sample period. That is, $i = Hong\ Kong$, *Russia*, *US*, *Argentina*, *Brazil*, *Greece*. The regime switching model is estimated using Bayesian techniques and is specified using prior information on the triggers of each crisis and is similar in concept to Chan et al. (2013). The dates chosen by the regime switching model are used as an input into the tests for contagion by searching for the transmission of contagion to other asset markets using the crisis dates for the source country.[4]

Consider the univariate normal distribution of asset returns for crisis country i, $z_{i,t}$ which allows the parameters of the mean and variance to be state dependent:

$$z_{i,t} = \mu_{i,s_t} + \varepsilon_{i,t}, \tag{1}$$

$$\varepsilon_{i,t} \overset{iid}{\sim} N\left(0, \sigma^2_{i,s_t}\right), \tag{2}$$

where regime $s_{i,t}$ at time t is assumed to have two states, $s_{i,t} \in \{0, 1\}$. The state $s_{i,t} = 0$ is a non-crisis period and $s_{i,t} = 1$ is a crisis period. The regime process is assumed to be independent of its own past history

$$\Pr\left(s_{i,t} = 1 | s_{i,t-1} = 0\right) = \Pr\left(s_{i,t} = 1 | s_{i,t-1} = 1\right) = p_t, \tag{3}$$

[4]Future work should analyze the links between each crisis as policy responses to a crisis may sow the seeds of the next crisis.

where the probability p_t is a fixed constant that varies with time. There are two sets of regime-dependent parameters in Eqs. 1 and 2. These are $\left(\mu_{i,0}, \sigma_{i,0}^2\right)$ and $\left(\mu_{i,1}, \sigma_{i,1}^2\right)$ for $s_{i,t} = 0$ and $s_{i,t} = 1$ respectively. The parameters of the complete regime switching model are $\Theta = \left(\mu_{i,0}, \mu_{i,1}, \sigma_{i,0}^2, \sigma_{i,1}^2\right)$.[5] For details see Appendix A.

The rest of the paper adopts the notation x_m and y_n to divide the data z_t into non-crisis and crisis periods respectively. There are $m = 1, ...6$ non-crisis periods and $n = 1, ...9$ crisis periods occurring throughout the sample. Similar to the crisis dating issues, defining a non-crisis period $x_{m,t}$ is also not straightforward. As is shown by the shading in Fig. 1 crisis periods can be clustered close together making it difficult to choose a non-crisis period not coinciding with the occurrence of other extreme events. As this paper is focused on examining multiple crises in several regions, care is taken to select the non-crisis periods as well. The principle for choosing the non-crisis periods is as follows: Consistent with information available to policy makers and portfolio decision makers in real time, where possible the data in the period preceding the crisis is used as the non-crisis data; when crises overlap each other whereby a useful tranquil period immediately preceding each crisis is not available, the previous pre-crisis data is used. The results of the dating of the crises are given in Section 3.2.

2.2 Contagion Testing Methods

The extent of the transmission of each crisis through new transmission channels is analyzed using the contagion tests of Fry et al. (2010) and Hsiao (2012). The tests each seek to identify a significant change in the distribution of the returns across a non-crisis and crisis period using different comoments of asset returns. The tests are the correlation test (CR) for changes in the transmission of shocks from the mean of market i to the mean of recipient j; the coskewness test (CS_1) for changes in shocks from the mean of market i to the volatility of recipient j; the second version of the coskewness test (CS_2) for the transmission of shocks from the volatility of market i to the mean of recipient j; and the covolatility test (CV) for the transmission of shocks from the volatility of market i to the volatility of recipient j. The tests are restated below with full derivations available in Fry et al. (2010) for the CR, CS_1 and CS_2 tests and Hsiao (2012) for the CV test. As the CV test in unpublished, the appendix provides a summary of its derivation.[6]

[5] Beliefs about the likelihood of crisis episodes occurring are incorporated formally via the prior probabilities $p_t = \Pr(s_t = 1) = 1 - \Pr(s_t = 0)$. The probability of being in a crisis is set to $\Pr(s_t = 1) = 0.9999$ from the likely trigger date of each crisis running to a logical end date of each crisis. These dates are chosen based on the discussion in Section 3.2. When it is less likely that the regime is a non-crisis period, $\Pr(s_t = 0) = 0.0001$.

[6] A Monte Carlo study of the first three tests of this paper are included in Dungey et al. (2013) and the sampling properties of the fourth test are examined in Hsiao (2012). The results show that the tests perform reliably, particularly once the correction in the correlation tests included here included in the formula. Size adjusted critical values determined in these works are used.

2.2.1 *Correlation Contagion Test (CR)*

The correlation test for contagion in Fry et al. (2010) extends early forms of the correlation change contagion tests of King and Wadhwani (1990) and Forbes and Rigobon (2002). The statistic for the transmission of contagion through the correlation channel *(CR)* based on the significance of a change in the adjusted crisis period correlation $\left(\widehat{\nu}_{y|x_i}\right)$ compared to a non-crisis period correlation $(\widehat{\rho}_x)$ from source market i to recipient j is

$$CR(i \to j) = \left(\frac{\widehat{\nu}_{y|x_i} - \widehat{\rho}_x}{\sqrt{Var\left(\widehat{\nu}_{y|x_i} - \widehat{\rho}_x\right)}} \right)^2, \tag{4}$$

with sample sizes T_x and T_y respectively so that $z_t = \left(x_1, x_2, ..., x_{Tx}, y_1, y_2, ..., y_{T_y}\right)$.[7]

2.2.2 *Coskewness Contagion Test* (CS_1)

The test of the transmission of contagion from the mean ($a = 1$) of asset i to the volatility ($b = 2$) of j through changes in the non-crisis coskewness coefficient $\left(\widehat{\psi}_x\right)$ compared to the crisis period coskewness coefficient $\left(\widehat{\psi}_y\right)$ is denoted $CS_1\left(i \to j; r_i^1, r_j^2\right)$ and is

$$CS_1\left(i \to j; r_i^1, r_j^2\right) = \left(\frac{\widehat{\psi}_y\left(r_i^1, r_j^2\right) - \widehat{\psi}_x\left(r_i^1, r_j^2\right)}{\sqrt{\frac{4\widehat{\upsilon}^2_{y|x_i} + 2}{T_y} + \frac{4\widehat{\rho}_x^2 + 2}{T_x}}} \right)^2, \tag{5}$$

where the coskewness statistics are

$$\widehat{\psi}_y\left(r_i^a, r_j^b\right) = \frac{1}{T_y} \sum_{t=1}^{T_y} \left(\frac{y_{i,t} - \widehat{\mu}_{y_i}}{\widehat{\sigma}_{y_i}} \right)^a \left(\frac{y_{j,t} - \widehat{\mu}_{y_j}}{\widehat{\sigma}_{y_j}} \right)^b, \tag{6}$$

$$\widehat{\psi}_x\left(r_i^a, r_j^b\right) = \frac{1}{T_x} \sum_{t=1}^{T_x} \left(\frac{x_{i,t} - \widehat{\mu}_{x_i}}{\widehat{\sigma}_{x_i}} \right)^a \left(\frac{x_{j,t} - \widehat{\mu}_{x_j}}{\widehat{\sigma}_{x_j}} \right)^b. \tag{7}$$

[7] The adjusted correlation coefficient

$$\widehat{\nu}_{y|x_i} = \frac{\widehat{\rho}_y}{\sqrt{1 + \delta\left(1 - \widehat{\rho}_y^2\right)}},$$

removes the bias caused by increasing volatility in asset returns in the source market during crises. The term $\delta = \frac{s^2_{y,i} - s^2_{x,i}}{s^2_{x,i}}$ is the proportionate change in the volatility of returns in the source equity market i, where $s^2_{x,i}$ and $s^2_{y,i}$ are the sample variances of equity returns in market i during the non-crisis and crisis periods. The correlation test is different to that of Forbes and Rigobon (2002) as the test statistic constructed in Fry et al. (2010) uses non-overlapping data.

The terms $\mu_{y_i}, \mu_{y_j}, \mu_{x_i}, \mu_{x_j}$ are the mean of the equity returns of each market in the crisis and non-crisis periods, and $\sigma_{y_i}, \sigma_{y_j}, \sigma_{x_i}, \sigma_{x_j}$ are the corresponding standard errors.

2.2.3 Coskewness Contagion Test (CS_2)

The second version of the coskewness contagion test statistic is denoted CS_2

$$CS_2\left(i \to j; r_i^2, r_j^1\right) = \left(\frac{\widehat{\psi}_y\left(r_i^2, r_j^1\right) - \widehat{\psi}_x\left(r_i^2, r_j^1\right)}{\sqrt{\frac{4\widehat{\upsilon}^2_{y|x_i} + 2}{T_y} + \frac{4\widehat{\rho}^2_x + 2}{T_x}}} \right)^2. \tag{8}$$

The $CS_2\left(i \to j; r_i^2, r_j^1\right)$ is a test for contagion through new spillovers from the volatility ($a = 2$) of the equity returns of the crisis market to the mean ($b = 1$) of the equity market returns of the recipient country.

2.2.4 Covolatility Contagion Test (CV)

The covolatility contagion test statistic is denoted CV

$$CV\left(i \to j; r_i^2, r_j^2\right) = \left(\frac{\widehat{\psi}_y\left(r_i^2, r_j^2\right) - \widehat{\psi}_x\left(r_i^2, r_j^2\right)}{\sqrt{\frac{4\widehat{\upsilon}^4_{y|x_i} + 16\widehat{\upsilon}^2_{y|x_i} + 4}{T_y} + \frac{4\widehat{\rho}^4_x + 16\widehat{\rho}^2_x + 4}{T_x}}} \right)^2, \tag{9}$$

where

$$\widehat{\psi}_y\left(r_i^2, r_j^2\right) = \frac{1}{T_y}\sum_{t=1}^{T_y}\left(\frac{y_{i,t} - \widehat{\mu}_{yi}}{\widehat{\sigma}_{yi}}\right)^2\left(\frac{y_{j,t} - \widehat{\mu}_{yj}}{\widehat{\sigma}_{yj}}\right)^2 - \left(1 + 2\widehat{\upsilon}^2_{y|x_i}\right)$$

$$\widehat{\psi}_x\left(r_i^2, r_j^2\right) = \frac{1}{T_x}\sum_{t=1}^{T_x}\left(\frac{x_{i,t} - \widehat{\mu}_{xi}}{\widehat{\sigma}_{xi}}\right)^2\left(\frac{x_{j,t} - \widehat{\mu}_{xj}}{\widehat{\sigma}_{xj}}\right)^2 - \left(1 + 2\widehat{\rho}^2_x\right).$$

The $CV\left(i \to j; r_i^2, r_j^2\right)$ tests for contagion through new spillovers from the volatility ($a = 2$) of the returns of the crisis market to the volatility ($b = 2$) of the returns of the recipient country.

2.2.5 Hypotheses

The null and alternative hypotheses of no contagion between two equity markets are

$$H_0 : \nu_{y|x_i} = \rho_x,$$
$$H_1 : \nu_{y|x_i} \neq \rho_x,$$

for the correlation channel, and

$$H_0 : \psi_y\left(r_i^a, r_j^b\right) = \psi_x\left(r_i^a, r_j^b\right),$$

$$H_1 : \psi_y\left(r_i^a, r_j^b\right) \neq \psi_x\left(r_i^a, r_j^b\right),$$

for the coskewness ($a = 1, b = 2$; and $a = 2$; $b = 1$) and covolatility ($a = b = 2$) channels. Under the null of no contagion, the correlation and coskewness tests are each asymptotically distributed as $CR(i \to j), CS_1(i \to j)$, $CS_2(i \to j)$, $CV(i \to j)$ $\xrightarrow{d} \chi_1^2$.

3 Nine Episodes of Crises and Contagion

This section summarizes the properties of the data used in the empirical analysis and discusses the dates chosen for each crisis which are then used in analyzing contagion.

3.1 The Data

The crises of this paper correspond to those in: Hong Kong (Asian crisis) in 1997–1998; Russia in 1998; the US (LTCM crisis) in 1998; Brazil in 1999; the US (dot-com crisis) in 2000; Argentina in 2001–2002; the US (sub-prime crisis) in 2007–2008; the US (great recession) in 2008–2009; and Greece (European debt crisis) in 2010–2013. The sample for the $k = 27$ equity markets represented in Fig. 1 consists of daily equity price indices $P_{k,t}$ expressed in US dollars.[8] The choice of countries in the sample is comparable to the set of Forbes and Rigobon (2002) and covers a selection of: emerging markets; developed markets; regions; markets that are the source of a crisis; and others not directly involved.[9] The markets are separated into emerging and OECD countries for the analysis as classified by the OECD. The 11 emerging countries grouped in regions include: (Asia) China, Hong Kong, India, Malaysia, the Philippines, Taiwan, Thailand; (Latin America) Argentina, Brazil; (Other) Russia and South Africa. The 16 OECD countries include: (Asia) Australia, Japan, Korea; (Europe) Belgium, France, Germany, Greece, the Netherlands, Spain, Sweden, Switzerland, the UK; (Latin America) Chile, Mexico; (North America) Canada and the US.

The data is transformed and adjusted following the precedents set in Forbes and Rigobon (2002). Daily percentage equity returns $R_{k,t}$ of market k are calculated as

$$R_{k,t} = 100(\ln(P_{k,t}) - \ln(P_{k,t-1})).$$

[8]All data are collected from Datastream

[9]Forbes and Rigobon include Singapore in their sample which we don't, as the current equity index for Singapore (The Straits Times Index) is only available from 1999 and the interest rate which constitutes a control in Forbes and Rigobon is also incomplete for the sample period.

The tests are conducted net of domestic market conditions and cross-market interdependencies existing in all states. These are controlled for through the effects of $\varphi(L)$ and $\phi(L)$ in a VAR of the form

$$R_t = \varphi(L)R_t + \phi(L)F_t + z_t,$$

where F_t contains relevant observable economic data for all markets, $\varphi(L)$ and $\phi(L)$ are parameter vectors of lags of $p = q = 5$, and z_t is the vector of residuals which are used as the returns in the calculation of the test statistics in Section 5. In the empirical application F_t contains the short term interest rates for the k markets being one of the few variables available at a daily frequency able to capture macroeconomic aspects of the economy which also affect equity markets. The data is adjusted by using the two day rolling average of returns to control for time zone effects. The sample size is $T = 4538$ and the effective sample period is September 12, 1995 to January 31, 2013.

3.2 Crisis Dating and Triggers

A summary of each crisis along with the dating of the non-crisis and crisis periods is contained in this section. Figure 2 presents the results of the dating of each crisis using the regime switching model of Section 2.1, where for source crisis countries a value of 1 represents a crisis and a value of 0 represents a non-crisis period. The dates chosen for each crisis episode as informed by the regime switching model analysis are shaded in the diagram and are summarized in Table 1.

3.2.1 Asia

The first panel of Fig. 2 documenting the period of crisis in Hong Kong shows that the Asian crisis $y_{1,t}$ extends from 20 October, 1997 to January 30, 1998 ($T_{1,y} = 75$). The trigger is the speculative attack on the Hong Kong currency and equity markets on 20 October, 1997 where in the regime switching model, $\Pr(s_{1,t} = 1) = 0.9999$. It is common to use October 20 as the start date of the crisis, with the alternative corresponding to the devaluation of the Thai baht in July, 1997 (see Corsetti et al. 2005; Dungey et al. 2006; Forbes and Rigobon 2002 and Table 9 in Appendix C). As equity markets are the focus of this paper, the Hong Kong attack is the source here. The end date of January 30, 1998 where $\Pr(s_{1,t} = 0) = 0.0001$ is consistent with most work on this crisis as outlined in Table. The pre-Asia non-crisis period $x_{1,t}$ extends from 12 September, 1995 to 17 October, 1997.

3.2.2 Russia and LTCM

The Russian crisis $y_{2,t}$ begins on August 17, 1998 and ends December 31, 1998 ($T_{2,y} = 99$) as shown in Fig. 2. The Russian Government deferred bond repayments on this date, marking the beginning of extreme asset market volatility and where $\Pr(s_{2,t} = 1) = 0.9999$. The majority of work on Russia summarized in Table 10 in Appendix C chooses the crisis period for Russia to be either early- or mid-August. The near collapse of the hedge fund Long Term Capital Management, known as the

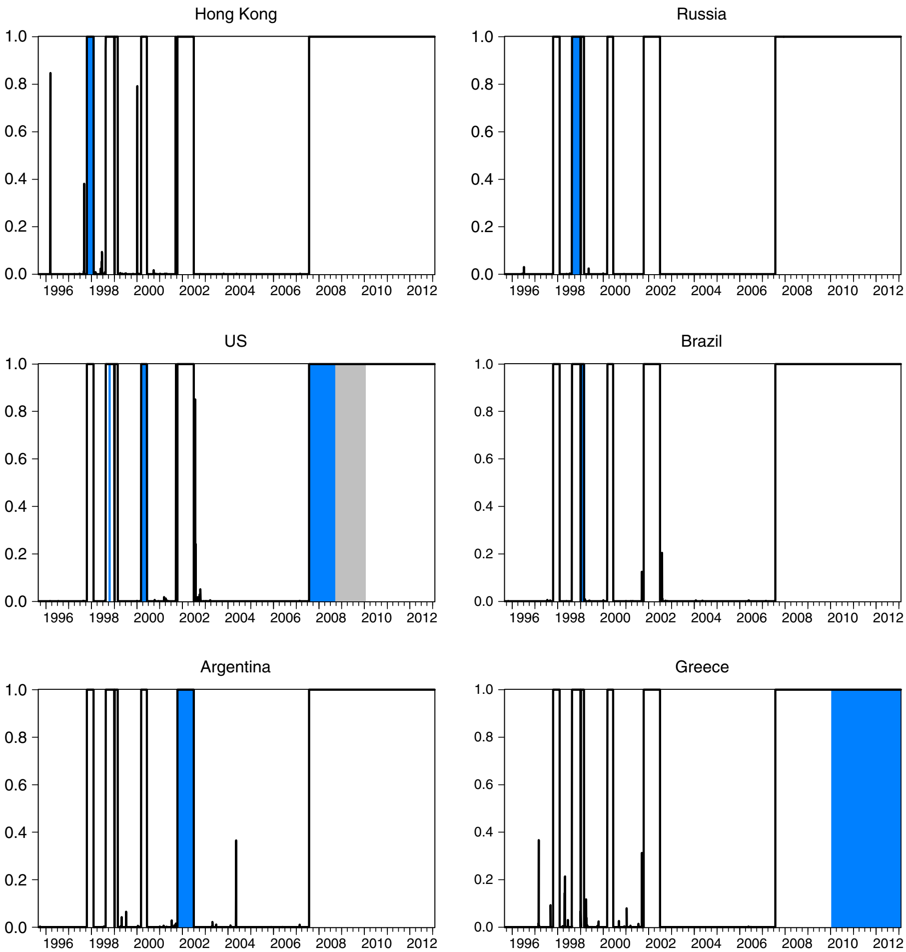

Fig. 2 Dating of the crises via the regime switching model. A value of one represents a crisis in each market. The shaded areas correspond to the dates of the source crisis country

LTCM crisis $y_{3,t}$ is linked to events in Russia and is nested within the Russian crisis period. The beginning coincides with the Federal Reserve of New York bailout of LTCM on September 23, 1998 ($\Pr(s_{3,t} = 1) = 0.9999$), and ends with the inter-FOMC interest rate cut on October 15 when ($\Pr(s_{3,t} = 0) = 0.0001)(T_{3,y} = 17)$. See Dungey et al. (2007) and Committee on the Global Financial System (1999). The non-crisis period $x_{1,t}$ is used to avoid any residual turmoil from the Asian crisis occurring between February and August 1998.

3.2.3 *Brazil*

For the Brazilian crisis $y_{4,t}$, the date that $\Pr(s_{4,t} = 1) = 0.9999$ is chosen as January 7, 1999 as substantial foreign reserves were lost in the week prior to the devaluation

Table 1 Crisis and non-crisis period dates

Crisis and non-crisis periods	Start of period	End of period	Obs.
(i) Crisis period dates $(y_{n,t})$			
Asia $(y_{1,t})$	20 October 1997	30 January 1998	75
Russia $(y_{2,t})$	17 August 1998	31 December 1998	99
LTCM $(y_{3,t})$	23 September 1998	15 October 1998	17
Brazil $(y_{4,t})$	7 January 1999	25 February 1999	36
Dot-com $(y_{5,t})$	7 March 2000	7 June 2000	67
Argentina $(y_{6,t})$	11 October 2001	30 June 2002	187
Sub-prime $(y_{7,t})$	26 July 2007	14 September 2008	297
Great recession $(y_{8,t})$	15 September 2008	31 December 2009	339
European debt $(y_{9,t})$	1 January 2010	31 January 2013	805
(ii) Non-crisis period dates $(x_{m,t})$			
Pre Asia $(x_{1,t})$	12 September 1995	17 October 1997	549
Pre Russia, post Asia $(x_{2,t})$	31 January 1998	14 August 1998	140
Pre Brazil, post Russia $(x_{3,t})$	1 January 1999	6 January 1999	4
Pre dot-com, post Brazil $(x_{4,t})$	26 February 1999	6 March 2000	267
Pre Argentina, post dot-com $(x_{5,t})$	8 June 2000	10 October 2001	350
Pre Sub-prime/great recession, post Argentina $(x_{6,t})$	7 January 2002	25 July 2007	1323

of the real which occurred on January 15. The trigger of the Brazilian crisis $y_{4,t}$ is a currency devaluation. The end of the crisis ($\Pr(s_{4,t} = 0) = 0.0001$) corresponds to a revised IMF program on February 25, 1999 which appears to calm markets ($T_{4,y} = 36$). As the crisis in Brazil began just one week following the end of the Russian crisis, the pre-Asia non-crisis period $x_{1,t}$ is also used.

3.2.4 Dot-com

The dot-com crisis $y_{5,t}$ occurring when the speculative bubble surrounding the dot-com industries collapsed extends from March 7, 2000 (with $\Pr(s_{5,t} = 1) = 0.9999$) and ends June 7, 2000 ($T_{5,y} = 67$). This crisis is probably the least dramatic of the crises sourced in the US market with it mainly affecting one sector of the economy. However, at the time the real and transmitted effects were uncertain. The non-crisis period $x_{4,t}$ extends from February 26, 1999 to March 6, 2000 between the Brazilian and dot-com crises. The crisis dates correspond to Dungey et al. (2009).

3.2.5 Argentina

Apart from the great recession, the Argentinian crisis $y_{6,t}$ is longest in duration ($T_{6,y} = 187$). The trigger of the crisis is just before the introduction of a partial deposit freeze and capital controls on October 11, 2001 with $\Pr(s_{6,t} = 1) = 0.9999$) (Cifarelli and Paladino 2004). The end date as displayed in Fig. 2 is June 30, 2002.

This period includes the collapse of the currency board in 2002. See International Monetary Fund (2003) for a comprehensive overview. The literature finds this crisis is harder to date that others. Dungey et al. (2009) and Wälti and Weder (2008) use mid 2005 which coincides with the return of Argentina to the voluntary bond market. The non-crisis period $x_{5,t}$ extends from June 8, 2000 to October 10, 2001 and is between the dot-com and Argentinian crises.

3.2.6 Sub-prime, great recession and European debt crisis

The final three crises considered are the sub-prime crisis $y_{7,t}$, the great recession $y_{8,t}$ and European debt crisis $y_{9,t}$. These three crises could be considered to be the one event and the regime switching model has difficulty separating the phases. However, the sub-prime and great recession are separated by the severity of the collapse of Lehman Brothers in September of 2008, and it is clear that the European debt crisis phase is different to the sub-prime and great recession phases. The start date of the sub-prime crisis coincides with heightened risk aversion and falls in liquidity from July 26, 2007 ($T_{7,t} = 297$). The great recession is defined to span from September 15, 2008 to December 31, 2009, ($T_{8,y} = 339$) days. The start date of the European debt crisis is chosen from January 1, 2010 to January 31, 2013, ($T_{8,y} = 805$) days. The non-crisis period for three of sub-prime, the great recession and European debt crisis $x_{6,t}$ extends from January 7, 2002 to July 25, 2007, between the Argentinian and sub-prime crises.

4 Hypothesized Contagion Channels

The number of crises and markets considered in this paper allows exploration of a range of hypotheses regarding the channels of contagion. As contagion is a change in the dependence structures between asset markets, it is natural to posit that linkages and relationships existing in normal periods are pre-conditions for contagion, and that it is changes in existing linkages through which contagion is likely to manifest rather than the addition of new linkages. This is akin to physical contact as a precondition for disease transmission in the health literature.

Theoretical models and the empirical literature suggest several channels through which contagion is likely to transmit. These channels are developed in this section and are used as benchmark for evaluation in the empirical results. For a summary of potential channels, see Goldstein et al. (2000), Forbes (2012) and Goldstein and Razin (2013). The major hypotheses considered in this paper examine likely channels of contagion through links arising from financial centers, trade, finance, regional proximity and development comparability. This section also describes the circumstances for each hypothesis prior to the crises.

4.1 Crises through Financial Centers

Reinhart and Rogoff (2008a, b) argue that a distinction needs to be made between a true global financial crisis and a severe financial crisis. They characterize a global financial crisis as one where a global financial center experiences a severe crisis and is in a position to transmit shocks systemically through financial flows emanating through that center. Kaminsky and Reinhart (2003) also argue that often a financial center is a conduit of a crisis across regions. They make the distinction that the center country does not need to be impacted itself, and does not need to be the trigger of the crisis but is a facilitator of the shock. This may occur through channels such as portfolio rebalancing or liquidity constraints. On the other hand, it may be that crisis in financial centers is less likely to be a source of contagion, as the macroeconomic factors that affect domestic markets are also strongly influenced by the US, and so the interdependencies between the US and other markets are already well accounted for. Hence it may not be surprising if there is no contagion arising from crises sourced in financial centers compared to those in emerging markets. As five of the nine crises considered in this paper are developed country sourced crises (LTCM, dot-com, subprime, the great recession and the European debt crisis), the prevalence of contagion coming from developed country crises compared to emerging market sourced crises is examined in Sections 5.1 and 5.2.

4.2 Trade and Finance

The obvious potential conduits of contagion are the major channels through which countries are economically linked, namely through trade and finance (Van Rijckeghem and Weder 2001; de Haas and van Horen 2013). Bilateral trade is affected by crises directly though a reduction in demand from the crisis affected country, and indirectly through relative competitiveness effects as exchange rates adjust.

If the hypothesis is that contagion is more likely for countries with strong trade linkages, then it is expected that the countries with the greatest trading links will be more affected by contagion than the rest of the countries in the sample. Table 2 presents the top 5 trading partners of the source crisis countries in the year prior to their crisis. For example, Hong Kong's major trading partners are China, the US, Japan, Singapore and Korea. Combined, these countries represent US$273.09 bn in exports and imports for Hong Kong which is around 70 % of trade for Hong Kong. If trade linkages are a facilitator of contagion, then these five countries are should be more affected by contagion than the remaining 21 countries in the sample.

During the Russian crisis the most likely countries in the sample to be affected by contagion if trade linkages are a conduit are Germany and the US (8 % and 5 % of total Russian trade respectively). During the US sourced LTCM crisis, it is Canada, Japan, Mexico, China and the UK which are the top trading partners, accounting for 52 % of total trade. The main trading partners of Brazil in the sample prior to its crisis are the US, Germany, Japan and the Netherlands, covering 38.37 % of total trade. For Argentina, they are Brazil, the US, Chile, China and Germany covering 55 % of trade. Prior to the subprime and great recession crises, the top trading partners of the US are Canada, China, Mexico, Japan and Germany, together accounting for 54 % of trade. Finally, for Greece the top trading partners are Germany, Italy, Russia, France and China covering 38 % of the export and import markets.

Table 2 The top 5 trading partners of crisis countries in the year prior to their crisis

Crisis country	Partners	Trade	% of total trade
Hong Kong (2001)	China	157.62	40.31
	US	55.90	14.30
	Japan	33.95	8.68
	Singapore	13.16	3.37
	Korea	12.46	3.19
Russia (1997)	Germany	13.17	7.93
	Ukraine	11.22	6.76
	Belarus	9.26	5.58
	US	9.01	5.43
	Italy	6.22	3.74
US (1997)	Canada	321.56	20.25
	Japan	189.94	11.96
	Mexico	158.55	9.98
	China	78.64	4.95
	UK	69.99	4.41
Brazil (1998)	US	24.82	22.20
	Germany	8.77	7.84
	Japan	5.78	5.17
	Italy	5.45	4.87
	Netherlands	3.53	3.15
Argentina (2000)	Brazil	13.47	26.16
	US	7.97	15.48
	Chile	3.28	6.37
	China	1.95	3.79
	Germany	1.86	3.61
US (2006)	Canada	538.08	18.20
	China	361.01	12.21
	Mexico	334.68	11.32
	Japan	211.89	7.17
	Germany	132.54	4.48
Greece (2009)	Germany	10.69	11.89
	Italy	10.13	11.27
	Russia	4.48	4.99
	France	4.47	4.97
	China	4.36	4.85

Value of trade (export plus imports) (US$bn) and percentage of total trade. The exception is Hong Kong, 2001 data substitutes for 1996 data as data for this period is missing. IMF's Direction of Trade Statistics

Financial linkages can take several forms, ranging from cross border exposures through the banking system and direct and portfolio investment. Over a wider financial system perspective, contagion may manifest indirectly through mechanisms such as wealth effects and portfolio rebalancing (Kyle and Xiong 2001), liquidity constraints, credit contractions (Matsuyama 2007), and investor behavior such as self fulfilling expectations (Masson 1999; Loisel and Martin 2001), information asymmetry (Yuan 2005), herd behavior (Kaminsky and Schmukler 1999; Krugman 1998; Calvo and Mendoza 2000) and central bank investment in risky foreign assets (Miller and Vallée 2011). This paper can only assess contagion through direct financial linkages because of a lack of information on indirect linkages.

Table 3 presents the top 5 portfolio investment partners of the crisis source countries in the year prior to their respective crisis. This table is divided into total portfolio investment, equity security investment and debt security investment. If finance linkages are a facilitator of contagion, then during the Asian crisis, the US, the UK, Australia, China, and Japan will be more affected by contagion than the rest of the countries in the sample. The table shows that of the countries in the sample, the US, the UK and Australia represent 43 % of total investment for Hong Kong. If only equity securities are considered, the UK, the US and China are among the top five equity investors with 42 % of the total. If only debt securities are considered, the US, Australia, the UK, and Japan are the largest with 55 % of total debt securities held by these countries.

For the Russian crisis, the US, Belgium and the Netherlands are the countries in the sample that should be more affected by contagion if financial linkages are a precursor of contagion. The US represents 16 % of all portfolio investment, Belgium accounts for 16 % of all equity investment, and the Netherlands represents 4 % of all debt securities investment. For the LTCM crisis, it is the UK, Canada, Japan, the Netherlands and Germany which are expected to be most affected by contagion through financial linkages. Combined, these countries account for 49 % of portfolio investment for the US. For Brazil, it is the US, Spain, Argentina, and the UK which are likely to be affected by contagion through finance linkages. For Argentina, it is the US, Spain, Brazil, Germany and Mexico (99 % of total portfolio investment), for the subprime and great recession period, it is the UK, Japan, Canada and France that are expected to be most affected (43 % of total portfolio investment), and for the European debt crisis, it is the UK (50 % of total portfolio investment), followed by the US, Germany and France, that are expected to be most affected.

4.3 Region and Development

Contagion is sometimes thought to be a geographical phenomenon and asset markets in a country are likely to be affected by contagion if there is a crisis in the region (Glick and Rose 1999; Caramazza and Ricci 2003; Dungey et al. 2009). Often the regional nature of the crisis is related to the previous hypotheses of the trade and finance based channels of contagion as these linkages are naturally expected to be relatively stronger in the neighborhood. Sometimes these channels may however operate in unexpected ways. For example, de Haas and van Horen (2013) find that banks reduce credit less to markets geographically close to them because of their better understanding of neighboring countries. Given the regional hypothesis, it is expected that the Asian countries be most affected by the crisis in Hong Kong, the European

Table 3 The top 5 portfolio investment partners of crisis countries prior to their crisis (US$bn)

Crisis country	Partners	Total	% of total	Partners	Equity sec.	% of total	Partners	Debt sec.	% of total
Hong Kong (2001)	US	39.25	19 %	UK	22.70	24 %	US	27.80	25 %
	UK	31.07	15 %	Bermuda	22.50	24 %	Australia	17.98	16 %
	Bermuda	22.71	11 %	Cayman Isl.	14.48	15 %	UK	8.37	8 %
	Cayman. Isl.	19.81	10 %	US	11.46	12 %	Japan	7.10	6 %
	Australia	18.58	9 %	China	5.45	6 %	Cayman Isl.	5.33	5 %
Russia (2001)	Luxembourg	0.42	32 %	Ukraine	0.03	30 %	Luxembourg	0.42	35 %
	Ukraine	0.25	19 %	Barbados	0.02	19 %	Ukraine	0.22	18 %
	US	0.21	16 %	Belgium	0.02	16 %	US	0.21	17 %
	Moldova	0.13	10 %	Bahamas	0.01	9 %	Moldova	0.13	11 %
	Bahamas	0.05	4 %	Bermuda	0.01	9 %	Netherlands	0.05	4 %
US (1997)	UK	270.14	16 %	UK	215.59	18 %	Canada	105.93	20 %
	Canada	176.07	10 %	Japan	135.28	11 %	UK	54.55	10 %
	Japan	165.42	10 %	Netherlands	106.03	9 %	Germany	43.17	8 %
	Netherlands	119.08	7 %	France	84.33	7 %	Japan	30.14	6 %
	Germany	107.67	6 %	Canada	70.14	6 %	Mexico	28.54	5 %
Brazil (2001)	US	1.88	39 %	Cayman Isl.	1.22	41 %	US	1.58	86 %
	Cayman Isl.	1.23	26 %	Spain	0.49	16 %	Bahamas	0.07	4 %
	Spain	0.53	11 %	US	0.30	10 %	UK	0.06	3 %
	Bahamas	0.23	5 %	Bahamas	0.16	5 %	Spain	0.03	2 %
	Argentina	0.12	2 %	Argentina	0.12	4 %	Cayman Isl.	0.02	1 %
Argentina (2001)	US	10.69	96 %	US	6.23	91 %	US	4.46	94 %
	Spain	0.42	4 %	Spain	0.40	6 %	Germany	0.06	1 %
	Brazil	0.11	1 %	Brazil	0.07	1 %	Brazil	0.04	1 %

Table 3 (continued)

Crisis country	Partners	Total	% of total	Partners	Equity sec.	% of total	Partners	Debt sec.	% of total
	Germany	0.08	1 %	UK	0.03	0.37 %	Austria	0.03	1 %
	Mexico	0.03	0.28 %	Germany	0.02	0.26 %	Spain	0.03	1 %
US (2006)	UK	1,075.58	18 %	UK	673.98	16 %	UK	401.60	24 %
	Japan	585.57	10 %	Japan	543.51	13 %	Cayman Isl.	214.99	13 %
	Canada	477.89	8 %	France	306.86	7 %	Canada	179.75	11 %
	France	397.30	7 %	Canada	298.14	7 %	France	90.43	6 %
	Cayman Isl.	375.54	6 %	Switzerland	262.62	6 %	Netherlands	72.57	4 %
Greece (2009)	UK	65.39	50 %	Luxembourg	7.72	54 %	UK	64.66	56 %
	Luxembourg	9.05	7 %	Cyprus	1.35	9 %	US	6.10	5 %
	US	7.07	5 %	US	0.98	7 %	Jersey	2.69	2 %
	Cyprus	2.78	2 %	UK	0.72	5 %	Germany	2.18	2 %
	Jersey	2.71	2 %	Romania	0.47	3 %	France	2.15	2 %

Total portfolio investment, equity security investment, debt security investment and percentage of total. For Hong Kong, 2001 data substitutes for 1996 data as data for this period is missing. Source: IMF's Coordinated Portfolio Investment Survey countries by the Russian crisis, Canada and the Latin American countries by the US sourced crises, the Latin American countries by the Brazilian and Argentinian crises and Europe during the European debt crisis.

The regional hypothesis is not dissimilar to the hypothesis where it is a country's level of development that matters. That is, if there is a crisis in an emerging market, it is likely that other emerging markets experience contagion as investors reassess other emerging markets where the underlying economic, financial market and policy settings may be similar to those of the crisis affected country. Likewise, as demonstrated through the sub-prime crises onwards, if there is a crisis in a developed market, it is likely that other developed markets experience contagion as investors reassess all developed markets. This sometimes formally occurs through internal risk grading mechanisms. Goldstein refers to this reassessment of countries with similar fundamentals in terms of wake up calls (Goldstein 1998). Lane (2013) touches on related issues by comparing the experiences of advanced and emerging countries during the recent crisis and further relating the differences back to the relationship of each country genre with financial globalization. To evaluate if it is similar levels of development of a country which is key for the transmission of contagion in this paper, the countries in the sample are separated into those in the OECD and those not in the OECD when investigating transmission differences.

4.4 Evaluating the Hypotheses

To explore the hypotheses listed above, three methods are used to compare the impact of contagion on the groups of countries identified in each case (for example major trading partners versus the remaining countries in the sample, or regional countries versus countries outside of the region). First, a simple analysis of the test statistics is conduct for each channel of contagion calculated over the crisis period from the source to the recipient countries. Second, the evolution and duration of contagion are evaluated using rolling test statistics of contagion calculated by taking the non-crisis period $\left(x_{m,t}\right)$ as fixed, and the four statistics are calculated using a rolling 30-day window of returns through the each crisis period. Third, equally weighted indexes of crisis severity are constructed using the rolling correlation, coskewness and covolatility tests to gauge the relative strength of contagion for different groups.

To calculate the indexes, an indicator variable $\left(I_{(i\rightarrow j),j,t}\right)$ is constructed for each recipient country j during each crisis which takes an integer value between 0 and 4. The value that the indicator takes depends on the number of test statistics for contagion at each period that are significant at the 0.05 level of significance such that

$$I_{(i\rightarrow j),j,t} = \begin{cases} 4: \text{if the p}-\text{values of the 4 tests are } \leq 0.05 \\ 3: \text{if the p}-\text{values of 3 of the tests are } \leq 0.05 \\ 2: \text{if the p}-\text{values of 2 of the tests are } \leq 0.05 \\ 1: \text{if a p}-\text{value of 1 of the tests is } \leq 0.05 \\ 0: \text{otherwise} \end{cases}, \qquad j \neq i. \quad (10)$$

To calculate the index of crisis severity then for each crisis

$$S(i \to j) = 100 \cdot \left(\frac{\sum_{j=1}^{26\times 4} I_{(i\to j),j,t}}{26 \times 4} \right). \tag{11}$$

If the index takes a value of 0, then over the previous 30 days there is no evidence of contagion for any of the 26 recipient countries through any of the channels. If the index takes a value of 100 then all 26 countries are affected by contagion from the source through all four channels.

To explore the relative importance of the top n trade or n finance partners compared to other markets in the sample, similar indexes are constructed for each subgroup. That is, for the top n group

$$S^{top}(i \to j) = 100 \cdot \left(\frac{\sum_{j=1}^{n\times 4} I_{(i\to j),j,t}}{n \times 4} \right) j = \text{top } n \text{ partners}, \tag{12}$$

and for the rest

$$S^{rest}(i \to j) = 100 \cdot \left(\frac{\sum_{j=1}^{(26-n)\times 4} I_{(i\to j),j,t}}{(26-n) \times 4} \right) j = \text{remaining } 26 - n \text{ countries}. \tag{13}$$

5 Empirical Results

5.1 Crises in Developed Markets

Five of the nine crises are sourced in the major financial centers of either the US or Europe and are suitable to analyze as potential true global financial crises. Tables 4, 5 and 6 present the correlation, coskewness and covolatility tests for the five crises with the source specified to be in a major financial center (LTCM, dot-com, subprime, the great recession and the European debt crisis).

The evidence indicates that the LTCM and dot-com crises did not manifest as true global financial crises (see Table 4). There are very few instances of contagion during the LTCM crisis with only 5 of the 104 possible channels operating. These are Argentina, South Africa and Mexico through the correlation channel, Greece through one of the coskewness channels, and the Philippines through the covolatility channel (panel (i) of Table 4). Likewise, there are few significant instances of contagion during the dot-com period (panel (ii) of Table 4), confirming that the dot-com crisis is contained within its own sector. Relationships between markets during the LTCM and dot-com crises are well accounted for by normal interdependencies.[10]

Turning to the crises of 2007–2013, the evidence supports Reinhart and Rogoff's suggestion that the great recession is a true global financial crisis at least in the contagion sense, and that this continues into the European debt crisis (see panels (ii) of

[10]Note the use of the finite sample critical values determined in Fry et al. (2011).

Table 4 Contagion from the US equity market *(i)* to recipient markets *(j)* during the (i) LTCM, and (ii) dot-com crises

Recip.(j)	Contagion tests							
	(i) Crisis: LTCM				(ii) Crisis: dot-com			
	CR	CS_1	CS_2	CV	CR	CS_1	CS_2	CV
Emerging markets								
Asia								
Chin.	2.50	0.01	0.26	0.00	0.29	2.70	3.14	1.54
HK.	0.00	0.29	0.07	1.10	0.19	2.75	0.22	1.37
Ind.	0.29	0.02	0.27	2.74	0.56	0.28	0.23	4.13*
Mal.	0.77	0.08	0.07	0.00	0.52	6.57*	1.51	2.88
Phi.	3.31	0.71	0.05	4.79*	1.25	0.21	0.98	0.17
Tai.	1.57	0.96	0.41	0.99	2.80	1.42	2.85	1.84
Thai.	1.30	1.42	0.01	2.21	0.10	0.00	0.00	2.89
Latin America								
Arg.	18.46*	0.00	0.01	0.01	0.02	0.27	0.19	3.16
Bra.	2.45	0.20	0.29	0.04	1.97	1.62	0.15	0.01
Others								
Rus.	0.16	0.37	0.39	0.01	4.27*	0.11	2.00	1.10
SoAF	4.49*	2.89	1.39	0.11	0.16	0.03	0.21	1.66
OECD markets								
Asia								
Aus.	3.15	0.23	0.41	1.00	3.68	0.02	2.97	0.23
Jap.	0.67	1.64	1.13	3.17	1.58	0.01	0.08	2.10
Kor.	0.65	1.35	0.05	0.05	0.16	0.04	0.23	0.28
Latin America								
Chil.	0.10	1.22	0.90	0.04	0.21	0.79	1.08	0.18
Mex.	17.68*	0.00	0.13	0.18	3.66	1.18	0.00	9.99*
Europe								
Bel.	1.61	0.01	0.09	0.05	0.16	6.84*	4.94*	4.28*
Fra.	1.27	1.22	0.01	0.10	0.23	0.36	0.56	1.47
Ger.	1.77	1.72	0.08	0.79	0.53	0.01	1.04	0.28
Gre.	2.71	7.62*	0.56	0.09	1.62	0.14	0.03	7.56*
Net.	2.02	0.12	0.60	0.03	0.78	0.49	0.00	2.12
Spa.	0.00	1.93	0.15	0.89	0.01	0.07	0.14	0.79
Swe.	1.66	0.01	0.02	3.48	0.02	0.02	0.85	0.04
Swi.	0.40	0.11	0.04	0.41	0.28	0.08	0.91	0.05
Others								
Can.	2.23	0.68	1.27	0.03	2.02	0.11	1.20	7.08*
UK	2.46	0.02	0.09	0.00	0.85	0.03	0.13	0.38

CR is the correlation contagion test in Eq. 4. CS_1 and CS_2 are the coskewness contagion tests in Eqs. 5 and 8. *CV* is the covolatility contagion test in Eq. 9. *denotes significance at the 5 % level

Table 5 Contagion from the US equity market *(i)* to recipient markets *(j)* during the (i) sub-prime, and (ii) great recession crises

Recip.(j)	Contagion tests							
	(i) Crisis: sub-prime				(ii) Crisis: great recession			
	CR	CS_1	CS_2	CV	CR	CS_1	CS_2	CV
Emerging markets								
Asia								
Chin.	3.13	2.50	4.64*	2.71	2.79	3.07	17.59*	8.39*
HK.	0.81	0.08	0.11	0.53	7.41*	0.32	5.26*	207.97*
Ind.	0.00	2.65	1.96	0.45	13.70*	3.70*	2.50	95.54*
Mal.	0.11	0.81	4.03*	8.67*	10.50*	0.00	1.04	49.96*
Phi.	3.76*	2.82	1.20	0.09	12.82*	9.67*	3.54	39.78*
Tai.	0.04	0.06	0.25	25.21*	0.07	0.95	2.24	33.18*
Thai.	0.52	0.75	6.00*	3.37	23.93*	19.45*	0.23	128.33*
Latin America								
Arg.	1.32	0.02	0.07	0.55	10.00*	4.10*	6.28*	184.62*
Bra.	0.02	0.81	4.03*	13.72*	1.62	0.00	0.48	184.60*
Others								
Rus.	0.06	0.68	1.09	0.06	0.76	5.35*	2.09	106.68*
SoAF	0.46	1.11	0.10	0.02	5.91*	8.59*	0.61	152.58*
OECD markets								
Asia								
Aus.	0.93	0.57	1.50	1.32	20.46*	2.95	0.75	134.29*
Jap.	2.01	0.83	0.56	0.84	0.20	2.56	0.05	0.05
Kor.	0.06	7.73*	3.04	0.33	4.16*	4.05*	3.86*	82.40*
Latin America								
Chil.	0.22	0.05	3.11	11.50*	3.42	13.08*	4.73*	285.35*
Mex.	0.00	0.82	0.91	9.69*	13.56*	0.12	0.32	89.38*
Europe								
Bel.	4.29*	0.22	0.67	66.83*	15.81*	9.09*	4.12*	13.75*
Fra.	13.27*	0.23	1.32	109.57*	24.73*	2.53	3.38	0.01
Ger.	1.71	0.63	0.66	15.45*	0.15	0.08	2.27	61.49*
Gre.	0.00	0.16	0.00	0.00	3.44	4.33*	0.05	32.61*
Net.	12.69*	0.42	2.43	133.45*	16.48*	12.84*	8.29*	2.06
Spa.	4.29*	1.54	0.13	40.29*	2.48	3.88*	1.23	29.02*
Swe.	5.23*	0.30	0.05	131.03*	11.80*	7.10*	3.60	9.70*
Swi.	6.66*	0.69	0.01	45.89*	10.10*	0.87	1.58	45.42*
Others								
Can.	12.73*	7.78*	17.68*	55.12*	5.85*	23.68*	23.40*	3.34
UK	3.54	2.04	0.04	63.40*	4.39*	7.07*	6.93*	33.05*

CR is the correlation contagion test in Eq. 4. CS_1 and CS_2 are the coskewness contagion tests in Eqs. 5 and 8. *CV* is the covolatility contagion test in Eq. 9. *denotes significance at the 5 % level

Table 6 Contagion from the US equity market (i) to recipient markets (j) during the (i) European debt crisis

Recip.(j)	Contagion tests			
	(i) Crisis: European debt			
	CR	CS_1	CS_2	CV
Emerging markets				
Asia				
Chin.	0.70	4.87*	5.83*	1.65
HK.	20.75*	0.20	1.69	9.42*
Ind.	16.07*	1.11	6.65*	0.12
Mal.	6.05*	3.40	3.45	1.19
Phi.	13.88*	3.40	1.17	6.45*
Tai.	6.51*	0.51	2.56	1.01
Thai.	13.97*	1.13	11.10*	0.33
Latin America				
Arg.	0.05	5.47*	0.01	27.80*
Bra.	1.76	0.11	2.14	13.31*
Others				
Rus.	3.97*	1.92	1.11	13.29*
SoAF	64.75*	0.01	0.10	1.71
OECD markets				
Asia				
Aus.	48.73*	3.35	0.01	19.04*
Jap.	32.85*	10.58*	0.27	34.24*
Kor.	9.25*	5.22*	3.23	19.42*
Latin America				
Chil.	23.13*	4.22*	3.50	2.92
Mex.	7.80*	0.20	1.53	6.64*
Europe				
Bel.	42.32*	8.13*	4.90*	13.40*
Fra.	26.26*	2.31	3.31	12.81*
Ger.	128.10*	5.73*	8.58*	8.75*
Gre.	n.a.	n.a.	n.a.	n.a.
Net.	17.62*	5.29*	3.35	10.37*
Spa.	62.75*	9.31*	6.30*	39.34*
Swe.	75.62*	0.04	1.05	0.56
Swi.	62.38*	1.59	0.09	5.84*
Others				
Can.	28.51*	1.01	0.13	10.26*
UK	44.23*	0.03	0.89	7.80*
US	0.20	0.20	0.58	37.21*

CR is the correlation contagion test in Eq. 4. CS_1 and CS_2 are the coskewness contagion tests in Eqs. 5 and 8. *CV* is the covolatility contagion test in Eq. 9. *denotes significance at the 5 % level

Table 5 and (i) of Table 6). The first phase of the 2007–2013 subprime crisis is characterized by interdependence with a medium level of contagion. Panel (i) of Table 5 shows contagion to all European countries through both the correlation and covolatility channels apart from to Greece (no contagion) and Germany (the covolatility channel only). The Latin American countries of Brazil, Chile and Mexico also display evidence of contagion through the covolatiltiy channel. There are few instances of contagion occurring through the coskewness channels during the subprime crisis.

The great recession and the European debt crisis are different to the other financial center crises in the sample with contagion widespread. In both crises, all channels are in operation with most countries experiencing contagion via a combination of transmission channels indicating again the importance of not just focusing on the correlation channel when examining contagion transmissions. The correlation and covolatility channels are most pervasive. The only country that is immune to the great recession is Japan with no contagion channels in operation. However, this changes during the European debt crisis.

As discussed in Section 2.1 on the dating of crises, it may not be the case that contagion operates for the entire duration of the crisis period. Contagion may be something that is fast moving (as is implied by many theoretical models such as models of herd behavior) as it may be the case that the markets are spooked at different times as a crisis evolves and recovery takes place. To examine the evolution and duration of contagion, rolling test statistics for each of the contagion types are computed and displayed in Figs. 3 and 4 for the great recession and the European debt crisis episodes respectively. These figures display the evolution of contagion over the crisis period through each of the four channels similar to that given in Eq. 11, but with the indexes calculated for each statistic rather than in the aggregate. The non-crisis period is held constant using $x_{6,t}$ and the test statistics are then calculated on a rolling basis using 30 observations in the calculation. The horizontal line represents the critical values, so the value of a test statistic recorded above this line is evidence of contagion in the previous 30 days.

Figure 3 highlights several important points regarding contagion during the great recession period. Overall, contagion is not significant on every day over the crisis period, but tends to appear in clusters at roughly the same time for groups of countries. The transmission channel which is most significant during this crisis is the correlation channel, followed by the covolatility channel. Evaluating contagion on a rolling basis also shows that while contagion can be insignificant over the total crisis period, countries can still be affected for short periods of time. The best instance of this is Japan where the test statistic in Table 5 did not show evidence of contagion, but over shorter intervals show periods where contagion is significant (see the panel for Japan in Fig. 3). Perhaps most interesting is that during the great recession contagion is strongest around the third quarter of 2009, and not immediately following the collapse of Lehman brothers in late 2008. This is true for both emerging and developed countries, although contagion post Lehman brothers is systematically significant for the European countries.

Figure 4 presents the same information for the European debt crisis period and the results are quite different. During the European debt crisis, contagion is persistent with the test statistics above the critical values more often than not. Again the

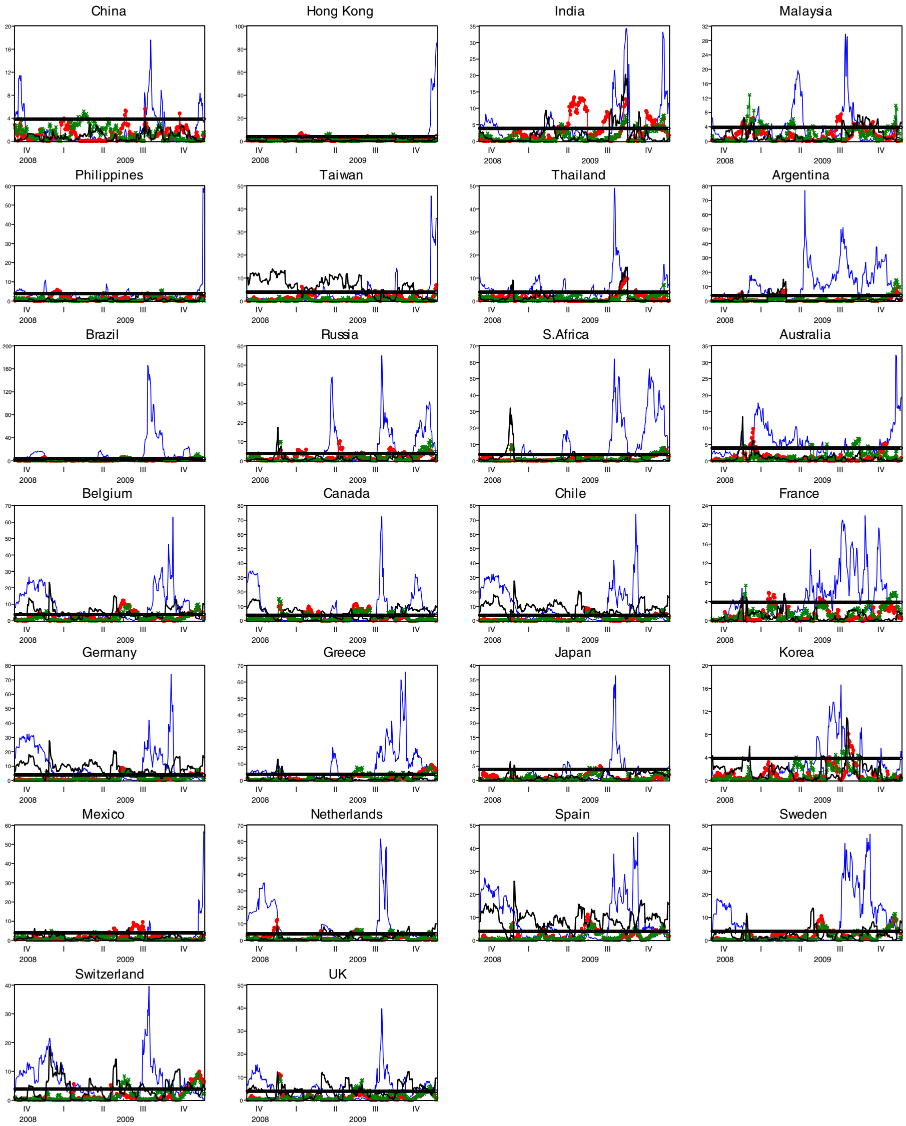

Fig. 3 Rolling test statistics of contagion from the US equity market ($i = 27$) during the great recession crisis to recipient markets (j) using the correlation test (*CR*), coskewness tests (CS_1 and CS_2) and covolatility test (*CV*). The contagion test statistics are calculated using a 30 day rolling period through the crisis period (27 October 2008–31 December 2009). The test statistics use $x_{6,t}$ in Table 1 as the pre-crisis period. The *horizontal line* is the 5 % χ_1^2 critical value. The *solid line*, *circled line*, *crossed line* and the *thick line* are the values of the test statistics of *FR*, CS_1, CS_2 and *CV* respectively

correlation channel is operational quite regularly but the covolatility channel is dominant compared to the great recession. The coskewness channels are operational relative to those channels during the great recession as well. Emerging markets appear

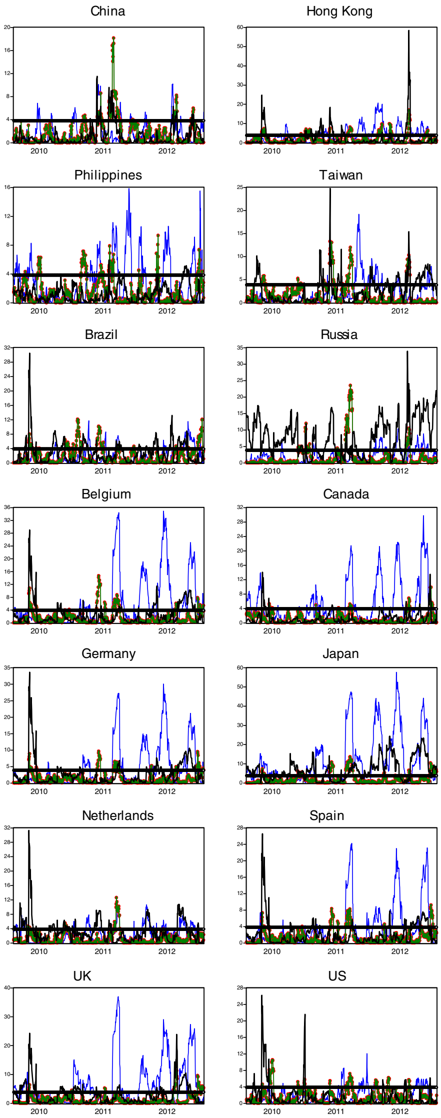

Fig. 4 Rolling test statistics of contagion from the Greek equity market ($i = 18$) during the European debt crisis to recipient markets (j) using the correlation test (CR), coskewness tests (CS_1 and CS_2) and covolatility test (CV). The contagion test statistics are calculated using a 30 day rolling period through the crisis period (12 February 2010–January 31 2013). The test statistics use $x_{6,t}$ in Table 1 as the pre-crisis period. The *horizontal line* is the 5 % χ_1^2 critical value. The *solid line*, *circled line*, *crossed line* and the *thick line* are the values of the test statistics of CR, CS_1, CS_2 and CV respectively

to be affected by contagion more during the European debt crisis than the great recession. The jitters evident for emerging markets begin appearing at the end of the great recession period in Fig. 3. For example, Hong Kong and the Philippines are barely affected by contagion during the great recession apart from a very short period at the end of the sample, but in the European debt crisis exhibit contagion for most of the period. Pappas et al. (2013) find similar results regarding the synchronization of contagion.

5.2 Crises in Emerging Markets

Perhaps unexpectedly compared to contagion from financial centers, contagion during crises sourced in emerging markets is consistently evident (see Tables 7 and 8). The crisis with the least evidence of contagion is the Russian crisis, where it is still the case that 10 of the 26 countries are affected through one of the channels: Hong Kong, the Philippines, Thailand and France through the correlation channel; Chile, Spain and South Africa through the coskewness channels; and Greece through the covolatility channel. During the other three emerging market crises (Asia, Brazil and Argentina), most countries are affected through one channel which is not necessarily the correlation channel. No one channel dominates, highlighting again that it is not just the correlation that should be considered but also market relationships through volatility.

Notably, it is often the developed markets that are affected by crises in the emerging markets through contagion. For the Asian and Brazilian crisis only 5 of 26 countries are not affected at all.[11] For the Argentinian crisis all countries are affected apart from Malaysia and Korea. For Brazil, only France, Korea and Spain are unaffected, with the remaining 23 countries affected through at least one channel. In contrast to the US sourced crises, the emerging crises seem to result in changes to the dynamics of shock transmission between the emerging and developed countries, providing some evidence that often financial centers are affected by emerging market crises (Kaminsky and Reinhart 2003).

To investigate the evolution and duration of contagion for an emerging market crisis, rolling test statistics of contagion are calculated similar to those in Figs. 3 and 4 for each crisis. The results for the Asian crisis are presented in Fig. 5.[12] During this crisis, nearly all countries in the sample experience some form of contagion in the initial phase, lasting for around two weeks. Thereafter, the transmission of shocks from Hong Kong to most of the non-Asian countries is no longer sustained. Exceptions to this include Russia and Brazil who experience their own crisis not long after, and Argentina, South Africa and France, although at a lower level compared to the immediate effects. The most active channels are the covolatility and the second coskewness channel (CS_2) channel, with some evidence of the correlation channel as well.

5.3 Trade or Finance

The indexes set out in Eqs. 11 to 13 for each crisis are displayed in Fig. 6. The solid line presents the indexes described in Eq. 11 which is calculated including all

[11] The five countries are different in each case.

[12] The figure of the rolling test statistics for the remaining crises are not presented to conserve space.

contagion channels for all of the 26 recipient countries. The figure also presents the same index calculated for the top $n = 5$ trade and finance partners of each of the source crisis countries (dotted line) along with an index calculated for the

Table 7 Contagion from the US equity market *(i)* to recipient markets *(j)* during the (i) Asian, and (ii) Russian crises

Recip.(j)	Contagion tests							
	(i) Crisis: Asia				(ii) Crisis: Russia			
	CR	CS_1	CS_2	CV	CR	CS_1	CS_2	CV
Emerging markets								
Asia								
Chin.	0.10	0.01	6.94*	0.43	0.09	2.00	0.46	0.01
HK.	n.a.	n.a.	n.a.	n.a.	4.87*	3.66	0.40	0.20
Ind.	1.61	0.00	0.03	0.00	0.34	0.76	2.77	0.23
Mal.	0.40	0.00	5.16*	31.32*	0.47	1.41	0.72	0.00
Phi.	0.04	1.23	2.89	7.25*	5.36*	0.38	0.00	0.77
Tai.	1.07	2.43	0.25	0.52	0.85	0.19	0.23	1.50
Thai.	2.12	0.06	0.78	5.50*	10.61*	1.17	0.81	1.07
Latin								
Arg.	0.31	1.54	4.81*	0.27	0.01	2.34	2.37	0.54
Bra.	0.94	1.10	2.63	0.00	0.79	1.30	6.65*	3.13
Others								
Rus.	3.58	0.04	0.04	48.98*	n.a.	n.a.	n.a.	n.a.
SoAF	5.82*	1.66	1.07	92.17*	0.00	7.99*	9.83*	0.59
OECD markets								
Asia								
Aus.	1.24	3.22	0.01	0.56	0.44	1.04	3.02	0.15
Jap.	1.83	0.36	0.86	5.39*	0.38	0.14	0.96	0.46
Kor.	3.84*	1.03	0.45	3.00	0.11	0.44	2.82	0.29
Latin America								
Chil.	2.84	2.38	5.88*	5.59*	0.34	6.87*	6.58*	0.23
Mex.	1.13	0.45	11.42*	15.33*	1.60	0.06	0.34	1.91
Europe								
Bel.	0.27	0.70	6.35*	7.19*	1.09	0.76	0.06	0.19
Fra.	0.19	0.98	4.58*	30.28*	6.48*	1.27	0.02	0.59
Ger.	0.18	0.94	0.09	7.08*	2.60	0.02	0.03	0.55
Gre.	3.96*	3.00	0.52	5.31*	1.39	0.00	1.06	5.09*
Net.	1.61	1.21	5.83*	4.28*	2.24	0.13	0.18	0.01
Spa.	0.45	3.26	7.10*	12.44*	0.44	4.46*	0.96	1.04
Swe.	0.01	7.19*	6.30*	27.83*	0.01	0.01	0.08	0.26
Swi.	0.00	0.02	2.25	0.86	0.61	0.09	0.74	0.00

Table 7 (continued)

Recip.(j)	Contagion tests							
	(i) Crisis: Asia				(ii) Crisis: Russia			
	CR	CS_1	CS_2	CV	CR	CS_1	CS_2	CV
Emerging markets								
Others								
Can.	0.02	4.69*	16.63*	25.41*	1.57	3.21	0.98	3.57
UK	0.43	3.88*	5.31*	14.31*	0.04	0.21	0.01	2.58
US	1.58	0.93	10.15*	14.63*	0.05	0.34	3.04	0.30

CR is the correlation contagion test in Eq. 4. CS_1 and CS_2 are the coskewness contagion tests in Eqs. 5 and 8. *CV* is the covolatility contagion test in Eq. 9. *denotes significance at the 5 % level

remaining countries (dashed line).[13] Starting with the crises that are not global financial crises, there is no systematic relationship between top trade or finance partners with contagion. Overall, for this form of crisis, trade and finance links do not necessarily accelerate changes in crisis transmission mechanisms, but the evidence indicates that strong financial linkages are more likely to be correlated with contagion transmission compared to trade links.

As Fig. 6 shows, for the Asian and dot-com crises there is little difference between contagion rates of the major trade and finance partners and the remaining countries. The results are different for Russia and Argentina. For Russia, during the first part of the crisis there is no distinction between rates of contagion for the top trade or finance partners. However this changes as the US (both a top trade and finance partner) experiences contagion in the latter half of the crisis through 3 of the 4 contagion channels, probably reflecting the US LTCM crisis nested within this period. For Argentina the top trading and finance partners are affected by contagion at a much greater rate compared to the remaining countries throughout the entire crisis period, probably reflecting the fundamental shift in the exchange rate policy in Argentina with the collapse of the currency board which affects trade. The other major policy change in Argentina was the restructuring of its debt repayments, affecting US bond holders in particular during this time and creating an international finance channel.

The great recession and European debt crises differ in terms of the characterization of their crisis periods. Strong finance linkages during the great recession are clearly facilitators of contagion, with the top finance partners substantially affected by the crisis. This is also the case during the preceding subprime crisis. This detail further reinforces the great recession as being a truly global financial crisis. In contrast, although the European debt crisis exhibits substantial contagion, there is not much

[13]Usually $n = 5$ but may be fewer depending on the description given in Section 4.2

of a distinction between rates of contagion of trade or finance partners affected by contagion, perhaps revealing the nature of the crisis as sovereign, compared to the US crises which seem to be financial crises.

Table 8 Contagion from the US equity market *(i)* to recipient markets *(j)* during the (i) Brazilian, and (ii) Argentinan crises

Recip.(j)	Contagion tests							
	(iii) Crisis: Brazil				(iv) Crisis: Argentina			
	CR	CS_1	CS_2	CV	CR	CS_1	CS_2	CV
Emerging markets								
Asia								
Chin.	1.83	0.24	0.90	0.00	0.32	0.01	23.42*	0.12
HK.	6.12*	1.15	0.45	3.99*	1.95	2.07	2.73	4.70*
Ind.	8.57*	0.59	0.08	0.20	0.55	5.87*	1.02	4.59*
Mal.	10.08*	0.05	1.74*	0.12	0.02	1.43	1.82	1.85
Phi.	6.59*	0.20	1.39	4.00*	0.01	7.39*	5.65*	0.24
Tai.	0.82	3.72*	1.54	1.07	0.97	0.40	10.80*	9.15*
Thai.	8.63*	0.97	0.34	0.84	2.04	0.30	0.28	7.32*
Latin America								
Arg.	0.11	1.81	2.87	17.39*	n.a.	n.a.	n.a.	n.a.
Bra.	n.a.	n.a.	n.a.	n.a.	101.95*	4.16*	4.34*	5.47*
Others								
Rus.	9.77*	2.91	0.88	2.04	7.17*	0.73	8.92*	0.92
SoAF	0.87	1.82	1.76	6.09*	28.63*	0.11	2.32	23.13*
OECD markets								
Asia								
Aus.	3.93*	2.88	9.32v	1.25	3.70*	0.01	4.94*	2.47
Jap.	7.39*	6.72*	2.39	1.13	0.08	1.36	1.30	6.73*
Kor.	0.90	0.24	0.06	1.53	0.31	0.58	1.28	0.93
Latin America								
Chil.	5.67*	0.11	0.65	6.54*	26.24*	1.09	16.43*	0.44
Mex.	13.30*	2.55	4.78*	10.25*	44.98*	0.00	6.48*	1.62
Europe								
Bel.	11.80*	0.11	0.07	2.08	26.67*	1.15	10.10*	5.16*
Fra.	2.09	0.32	0.94	0.05	33.57*	0.03	10.96*	0.56
Ger.	9.70*	1.04	1.28	0.21	20.80*	0.67	9.46*	3.98*
Gre.	6.12*	0.75	2.48	3.08	3.99*	0.30	3.57	0.55
Net.	1.58	2.71	5.66*	6.57*	30.30*	0.15	7.47*	2.28
Spa.	1.57	0.22	0.74	1.36	39.75*	0.87	36.88*	15.44*
Swe.	6.58*	0.19	2.67	1.47	24.20*	0.48	15.30*	3.20
Swi.	0.93	6.45*	2.13	0.00	22.33*	3.86*	0.53	4.85*

Table 8 (continued)

Recip.(j)	Contagion tests							
	(iii) Crisis: Brazil				(iv) Crisis: Argentina			
	CR	CS_1	CS_2	CV	CR	CS_1	CS_2	CV
Others								
Can.	3.80*	11.04*	2.49	1.74	21.69*	2.13	8.99*	0.30
UK	0.50	6.21*	4.78*	3.49	31.59*	0.16	28.23*	0.43
US	8.38*	0.06	0.22	0.00	25.35*	1.13	13.74*	1.79

CR is the correlation contagion test in Eq. 4. CS_1 and CS_2 are the coskewness contagion tests in Eqs. 5 and 9. *CV* is the covolatility contagion test in Eq. 9. *denotes significance at the 5 % level

5.4 Region and Development

To explore if crises are regional or if countries of similar levels of development to the source crisis market are more likely to experience contagion, the indexes of regional and developmental contagion are presented in Fig. 7. In each panel of the figure, the solid line presents the 30 day indicator of overall contagion. For the region panels, the remaining lines are the indicators of contagion for groups of countries with the characteristics of being in the same region as the source crisis market, being in the same region and being an emerging market, or being in the same region and being an OECD country. For the developed panels, the remaining lines are the indicators of contagion for groups of countries being either an emerging or an OECD country.

The only crisis which is mainly regional is the Argentinian crisis where all channels are operating for the regional emerging countries in Latin America (here Brazil). The advanced countries in the region (the US, Canada, Chile and Mexico) are also quite affected compared to total contagion coming from this crisis, with up to 90 % of the potential channels operating at the peak of contagion transmission. In contrast, the other Latin American crisis transmitting country of Brazil, the emerging Latin countries are affected at the same rate as in the overall sample, but this time the advanced regional countries are barely affected. The emerging market crisis in Asia indicates that as the crisis unfolds, the regional nature becomes stronger, particularly for the emerging regional countries, with little evidence of regional spillovers to the advanced Asian economies. However, it is interesting to note that in the beginning, there is more contagion ocurring system-wide compared to that ocurring regionally. For the crises in the developed markets, close inspection of the figure shows that the regional advanced countries tend to be more affected by contagion than either the emerging regional countries or compared to system-wide contagion. de Haas and van Horen (2013) also find that crises are not necessarily regional.

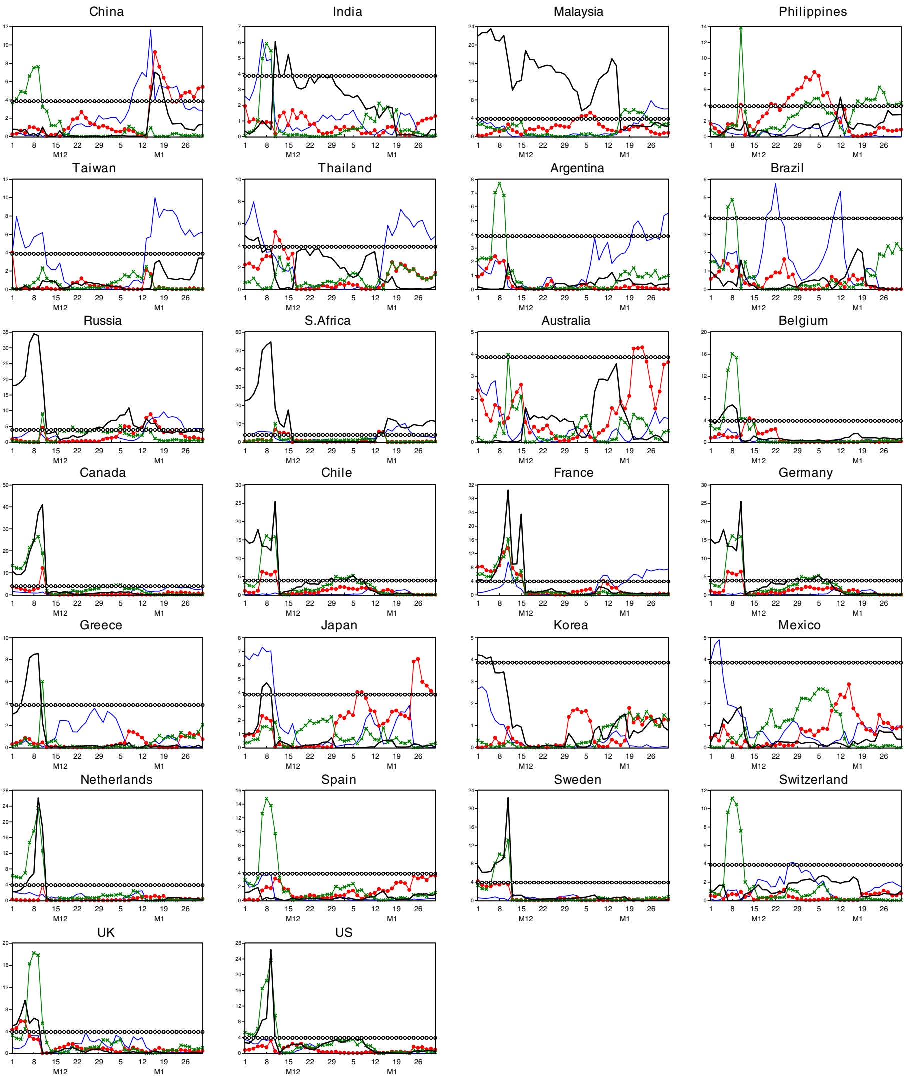

Fig. 5 Rolling test statistics of contagion from the Hong Kong equity market ($i = 2$) during the Asian crisis to recipient markets (j) using the correlation test (CR), coskewness tests (CS_1 and CS_2) and covolatility test (CV). The contagion test statistics are calculated using a 30 day rolling period through the crisis period (1 December 1997–30 January 1998). The test statistics use $x_{1,t}$ in Table 1 as the pre-crisis period. The *horizontal line* is the 5 % χ_1^2 critical value. The *solid line*, *circled line*, *crossed line* and the *thick line* are the values of the test statistics of FR, CS_1, CS_2 and CV respectively

Turning to the indicators of contagion for countries of different levels of development, the results are rather striking in that it is mainly the advanced countries that are affected by contagion in almost all crises, even from those with their source in the emerging markets. Inspection of the panels for development for the crises in Asia,

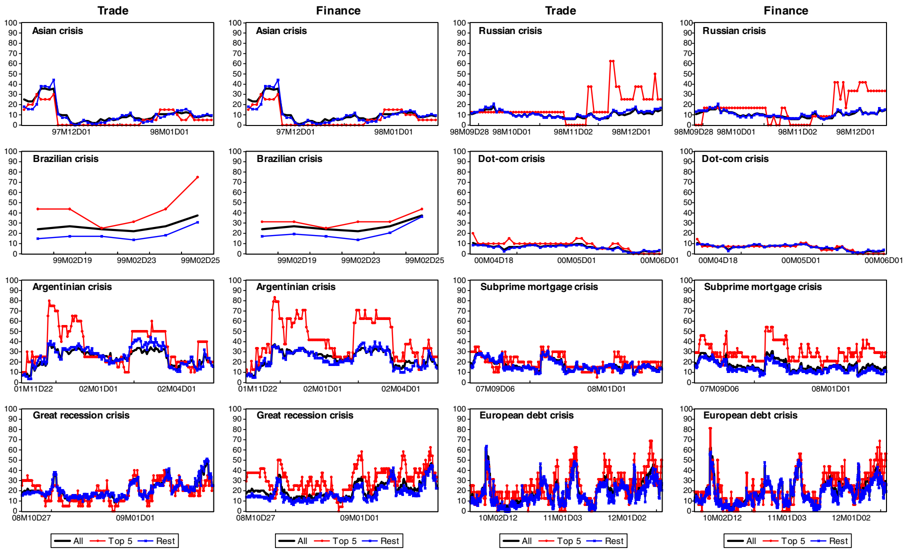

Fig. 6 Percentage of markets affected by contagion for each crisis. All markets, top 5 trade and finance partners and rest $(n - 5)$ of markets

Russia, Brazil and Argentina shows that with the exception of the last two thirds of the Asian crisis and a little of the Brazilian crisis, usually the incidence of contagion is greater for the OECD countries. For the developed market sourced crises, there is

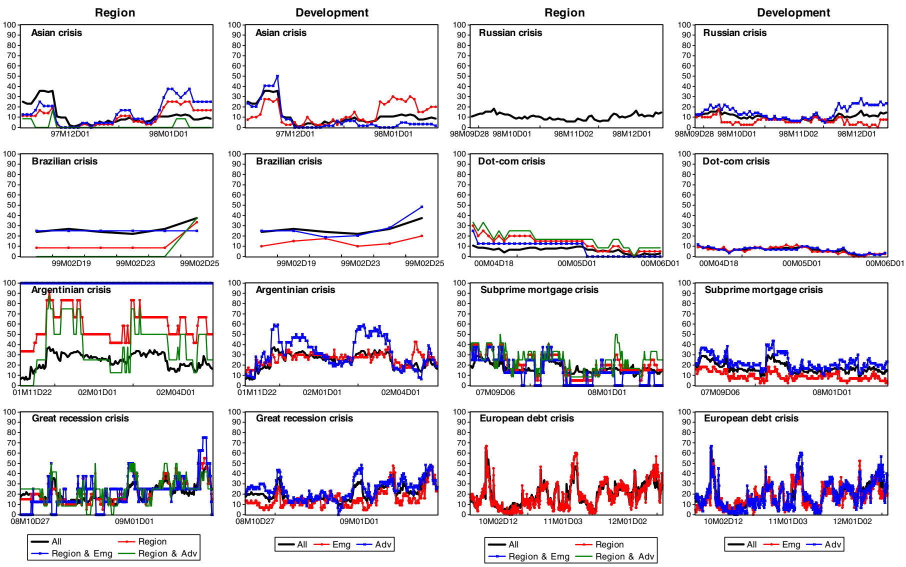

Fig. 7 Percentage of markets affected by contagion for each crisis. All markets, markets in crisis region (emerging/advanced) markets of development type (emerging/ advanced)

little to be said about the dot-com crisis. However, the subprime crisis and the great recession crisis systematically affects the OECD countries more than the emerging countries. The European debt crisis seems to affect all countries at a relatively equal rate.

6 Conclusions

This paper examines nine financial market crisis episodes ranging from Asia in 1997–1998 to the European debt crisis in 2010–2013 to establish some stylized facts regarding the transmission of crises from the countries that trigger the crisis to other markets through channels of contagion. The paper first uses a regime switching model to date the crisis in the source asset market. The dating for each crisis episode is then used as an input to the tests for contagion, avoiding subjective methods to date crisis periods for use in the analysis of contagion. Four tests for contagion are used to examine alternative transmission paths of contagion.

Contagion is a change in the dependence structures of asset returns in a crisis period compared to a non-crisis period. The paper examines the hypothesis that cross market interactions can result in contagion in unexpected ways. The tests look at the four cross market spillovers: i) between the market of the source crisis market with the market of a recipient market (correlation contagion); ii) between the source market and the volatility of a recipient market (coskewness 1 contagion); iii) between the volatility of the source market and the recipient market (coskewness 2 contagion); and iv) between the volatility of the source market and the volatility of a recipient market (covolatility contagion). The first three tests are taken from Fry et al. (2010). The fourth is introduced in this paper and builds on Hsiao (2012).

The transmission channel of contagion which is generally most prevalent is the correlation channel, followed by the covolatility channel. In the worst crises, the coskewness channels are also operational. The results indicate that all channels of contagion need to be examined during financial crises. It is not enough to focus only on the correlation channel. Overall, contagion is not significant on every day over the crisis period, but appears in clusters at roughly the same time for groups of countries. Contagion can be insignificant over the total crisis period and countries are often affected for short periods of time. This illustrates the importance of testing for contagion in crisis periods of short duration to avoid diluting the effects of crises.

The large number of crises in our sample and the variety of countries enable the assessment of several hypotheses regarding contagion transmission. The first is that crises sourced in financial centers transmit more contagion than other forms of crises, and that only crises in financial centers can be true global financial crises (Reinhart and Rogoff). The results indicate that the great recession and the European debt crisis are true global financial crises. In both crises, all channels are in operation with most countries experiencing contagion via a combination of transmission channels. Perhaps most interesting is that during the great recession, contagion is strongest around the third quarter of 2009, and not immediately following the collapse of Lehman brothers in late 2008. During the European debt crisis, contagion is persistent and widespread. Emerging markets appear to be affected by contagion more during the European debt crisis than the great recession. The LTCM and dot-com crises are well accounted for by normal interdependencies. Although not satisfying the Reinhart and Rogoff preconditions to be considered global financial crises, contagion during crises sourced in emerging markets is consistently evident, and it is often developed markets that are affected by emerging market crises.

The second hypothesis that is investigated is that trade and finance linkages facilitate contagion by providing an initial link for transmission of the crisis to occur. The results indicate that trade and finance links do not necessarily accelerate changes in crisis transmission mechanisms, but strong financial linkages are more likely to be correlated with contagion transmission compared to trade links. Strong finance linkages are clearly facilitators of contagion during the great recession, and although the European debt crisis exhibits substantial contagion, there is not very much of a distinction between rates of contagion for trading or finance partners for this particular crisis.

The third hypothesis examines whether regional proximity or similarity of level of development to a crisis source country leads to contagion. The results show that the only crisis which is regional is the Argentinian crisis. For the Asian crisis, as the crisis unfolds, the regional nature becomes stronger, particularly for the emerging regional countries, with little evidence of regional spillovers to the advanced Asian economies. However, it is interesting to note that in the beginning, there is more contagion system-wide relative to contagion region-wide. The subprime crisis and the great recession crisis systematically affects the OECD countries more than the emerging countries, while the European debt crisis seems to affect all countries at a relatively equal rate.

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Appendix A: Estimation of the Regime Switching Model

The regime switching model is used to estimate the crisis dates using knowledge of trigger events. Prior distributions are combined with the likelihood function to obtain the joint posterior distribution via the Bayes rule in a Bayesian estimation framework. The Gibbs sampler is then used to obtain draws from the joint posterior distribution required for the analysis.

The (complete-data) likelihood function of the model in Eqs. 1 to 2 is

$$f(y|\Theta, s) = (2\pi)^{-\frac{T}{2}} \prod_{t=1}^{T} \left|\sigma_{s_t}^2\right|^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}\sum_{t=1}^{T}\left[y_t - \mu_{s_t}\right]' \left(\sigma_{s_t}^2\right)^{-1} \left[y_t - \mu_{s_t}\right]\right\}, \tag{14}$$

where $\Theta = \left(\mu_0, \mu_1, \sigma_0^2, \sigma_1^2\right)$ and $s_t \in \{0, 1\}$. Here, $y = (y_1, \ldots, y_T)'$ and $s = (s_1, \ldots, s_T)'$.

The prior for the model parameters are specified as

$$\mu_{s_t} \sim N\left(\underline{\mu}, \underline{V}_\mu\right), \tag{15}$$

$$\sigma_{s_t}^2 \sim IW\left(\underline{\tau}_{\sigma^2}, \underline{S}_{\sigma^2}\right), \tag{16}$$

$$\Pr(s_t = 1) = p_t, \Pr(s_t = 0) = 1 - p_t, \tag{17}$$

where $IW\left(\underline{\tau}_{\sigma^2}, \underline{S}_{\sigma^2}\right)$ denotes the inverse-Wishart distribution with degree of freedom $\underline{\tau}_{\sigma^2}$ and scale matrix $\underline{S}_{\sigma^2}$. The prior mean and variance for μ_{s_t} are set to $\underline{\mu}$ and $\underline{V}_\mu = \phi_\mu$.

The joint posterior distribution is calculated by multiplying the prior distributions with the likelihood function via Bayes rule. Then, posterior draws from the joint posterior distribution are obtained via the Gibbs sampler:

Step1: Specify starting values for $\Theta^{(0)} = \left(\mu_l^{(0)}, \left(\sigma_l^2\right)^{(0)}\right)$ with $l = 0, 1$. Set counter $loop = 1, \ldots, n$.
Step2: Generate $s^{(loop)}$ from $\pi\left(s|y, \Theta^{(loop-1)}\right)$.
Step3: Generate $\mu_l^{(loop)}$ from $\pi\left(\mu_l|y, \left(\sigma_l^2\right)^{(loop-1)}, s^{(loop)}\right)$.
Step4: Generate $\left(\sigma_l^2\right)^{(loop)}$ from $\pi\left(\sigma_l^2|y, \mu_l^{(loop-1)}, s^{(loop)}\right)$.
Step5: Set $loop = loop + 1$ and go to Step 2.

The number of iterations set for Steps 2 to 4 is n. The first n_0 of these are discarded as burn-in draws, and the remaining n_1 draws are retained to compute the parameter estimates. The full conditional distributions are given below and their derivations are available on request.

The posterior distribution for μ_l, $l = 0, 1$, conditional on y, σ_0^2, σ_1^2 and s is an univariate normal distribution given by

$$\left(\mu_l|y, \sigma_l^2, s\right) \sim N\left(\widehat{\mu}_l, D_{\mu_l}\right), l = 0, 1,$$

where $D_{\mu_l} = \left(\underline{V}_\mu^{-1} + \left(\sigma_l^2\right)^{-1}\right)^{-1}$ and $\widehat{\mu}_l = D_{\mu_l}\left[\underline{V}_\mu^{-1}\underline{\mu} + \sum_{t=1}^{T} 1\left(s_t = l\right)\left(\sigma_{s_t}^2\right)^{-1} y_t\right]$.

The posterior distribution for σ_l^2, $l = 0, 1$, conditional on y, μ_0, μ_1 and s is an inverse-Wishart distribution

$$\left(\sigma_l^2 | y, \mu_l, s\right) \sim IW\left(\tau_{\sigma_l^2}, S_{\sigma_l^2}\right),$$

where $\tau_{\sigma_l^2} = \underline{\tau}_{\sigma^2} + \sum_{t=1}^{T} 1\,(s_t = l)$ and $S_{\sigma_l^2} = \underline{S}_{\sigma^2} + \sum_{t=1}^{T} 1\,(s_t = l)\left(y_t - \mu_{s_t}\right)\left(y_t - \mu_{s_t}\right)'$.

To generate regime variable s_t, the multi-move Gibbs sampling method is used. Since the regime variable s_t evolves independently of its own past values, the regimes $s_1, \ldots, s_T$ are conditionally independent of each other given the data and other parameters:

$$\pi\,(s|y, \Theta) = \prod_{t=1}^{T} \pi\,(s_t|y, \Theta),$$

where the success probability can be calculated as

$$\Pr(s_t = 1|y, \Theta) = \frac{\pi\,(s_t = 1|y, \Theta)}{\pi\,(s_t = 0|y, \Theta) + \pi\,(s_t = 1|y, \Theta)}.$$

Once the above probability is calculated, a random number from a uniform distribution between 0 and 1 is generated to compare with the calculated value of $\Pr(s_t = 1|y, \Theta)$. If the probability $\Pr(s_t = 1|y, \Theta)$ is greater than the generated number, the regime variable $s_t = 1$; otherwise, $s_t = 0$.

Appendix B: Derivation of the Covolatility Test Statistic for Contagion

This appendix summarizes the key points in the derivation of the covolatility statistic for contagion. Further details are presented in Hsiao (2012). Consider the following generalized exponential distribution which has as its base the bivariate normal distribution, but with the addition of fourth order comoments labelled covolatility:

$$\begin{aligned} f(r_{1,t}, r_{2,t}) = \exp\Bigg[&-\frac{1}{2}\left(\frac{1}{1-\rho^2}\right)\left(\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)^2 + \left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)^2\right. \\ &\left. -2\rho\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)\left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)\right) + \theta\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)^2\left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)^2 - \eta\Bigg], \end{aligned} \tag{18}$$

where $\eta = \ln \iint \exp[h] dr_1 dr_2$, and

$$h = -\frac{1}{2}\left(\frac{1}{1-\rho^2}\right)\left(\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)^2 + \left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)^2 \right.$$
$$\left. -2\rho\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)\left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)\right) + \theta\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)^2\left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)^2. \quad (19)$$

A test for bivariate normality in this distribution is a test of the parameter

$$H_0 : \theta = 0. \quad (20)$$

Let the parameters of Eq. 18 be $\Theta = \left\{\mu_1, \mu_2, \sigma_1^2, \sigma_2^2, \rho, \theta\right\}$. Under the null hypothesis, the maximum likelihood estimators of the unknown parameters are

$$\widehat{\mu}_i = \frac{1}{T}\sum_{t=1}^{T} r_{i,t};\ \widehat{\sigma}_i^2 = \frac{1}{T}\sum_{t=1}^{T}\left(r_{i,t}-\widehat{\mu}_i\right)^2;\ \widehat{\rho}$$
$$= \frac{1}{T}\sum_{t=1}^{T}\left(\frac{r_{1,t}-\widehat{\mu}_1}{\widehat{\sigma}_1}\right)\left(\frac{r_{2,t}-\widehat{\mu}_2}{\widehat{\sigma}_2}\right);\ i = 1, 2. \quad (21)$$

The log likelihood function of the expression in Eq. 18 at time t is

$$\ln L_t(\Theta) = -\frac{1}{2}\left(\frac{1}{1-\rho^2}\right)\left(\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)^2 + \left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)^2 \right.$$
$$\left. -2\rho\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)\left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)\right) + \theta\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)^2\left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)^2 - \eta$$
$$= h - \eta, \quad (22)$$

where h is given by equations (19) and $\eta = \ln \iint \exp[h] dr_1 dr_2$.

The asymptotic information matrix, derived in Fry et al. (2010), is

$$I_t(\Theta) = -E\left[\frac{\partial^2 \ln L_t(\Theta)}{\partial\Theta\partial\Theta'}\right]$$
$$= E\left[\frac{\partial h}{\partial\Theta}\frac{\partial h}{\partial\Theta'}\right] - E\left[\frac{\partial h}{\partial\Theta}\right]E\left[\frac{\partial h}{\partial\Theta'}\right]. \quad (23)$$

Using Eq. 23 and the properties of the bivariate normal distribution, the information matrix under H_0 is

$$
\begin{aligned}
I\left(\widehat{\Theta}\right) &= T\left(E\left[\frac{\partial h}{\partial \Theta}\frac{\partial h}{\partial \Theta'}\right]_{\theta=0} - E\left[\frac{\partial h}{\partial \Theta}\right]_{\theta=0} E\left[\frac{\partial h}{\partial \Theta'}\right]_{\theta=0}\right) \qquad (24)\\
&= \left(\frac{T}{1-\widehat{\rho}^2}\right)\times \\
&\begin{bmatrix}
\frac{1}{\widehat{\sigma}_1^2} & \frac{-\widehat{\rho}}{\widehat{\sigma}_1\widehat{\sigma}_2} & 0 & 0 & 0 & 0 \\
\frac{-\widehat{\rho}}{\widehat{\sigma}_1\widehat{\sigma}_2} & \frac{1}{\widehat{\sigma}_2^2} & 0 & 0 & 0 & 0 \\
0 & 0 & \frac{-\widehat{\rho}^2+2}{4\widehat{\sigma}_1^4} & \frac{-\widehat{\rho}^2}{4\widehat{\sigma}_1^2\widehat{\sigma}_2^2} & \frac{-\widehat{\rho}}{2\widehat{\sigma}_1^2} & \frac{(2\widehat{\rho}^2+1)(1-\widehat{\rho}^2)}{\widehat{\sigma}_1^2} \\
0 & 0 & \frac{-\widehat{\rho}^2}{4\widehat{\sigma}_1^2\widehat{\sigma}_2^2} & \frac{-\widehat{\rho}^2+2}{4\widehat{\sigma}_2^4} & \frac{-\widehat{\rho}}{2\widehat{\sigma}_2^2} & \frac{(2\widehat{\rho}^2+1)(1-\widehat{\rho}^2)}{\widehat{\sigma}_2^2} \\
0 & 0 & \frac{-\widehat{\rho}}{2\widehat{\sigma}_1^2} & \frac{-\widehat{\rho}}{2\widehat{\sigma}_2^2} & \frac{\widehat{\rho}^2+1}{1-\widehat{\rho}^2} & 4\widehat{\rho}\left(1-\widehat{\rho}^2\right) \\
0 & 0 & \frac{(2\widehat{\rho}^2+1)(1-\widehat{\rho}^2)}{\widehat{\sigma}_1^2} & \frac{(2\widehat{\rho}^2+1)(1-\widehat{\rho}^2)}{\widehat{\sigma}_2^2} & 4\widehat{\rho}\left(1-\widehat{\rho}^2\right) & \left(8+68\widehat{\rho}^2+20\widehat{\rho}^4\right)\left(1-\widehat{\rho}^2\right)
\end{bmatrix}.
\end{aligned}
$$

Evaluating the gradient of θ under the null gives

$$
\begin{aligned}
\frac{\partial \ln L_t}{\partial \theta} &= \sum_{t=1}^{T}\left(\frac{\partial h}{\partial \theta}\right) - T\left(\frac{\partial \eta}{\partial \theta}\right) \\
&= \sum_{t=1}^{T}\left(\frac{r_{1,t}-\mu_1}{\sigma_1}\right)^2\left(\frac{r_{2,t}-\mu_2}{\sigma_2}\right)^2 - T\left(1+2\rho^2\right). \qquad (25)
\end{aligned}
$$

The score function under the null is

$$
\begin{aligned}
q\left(\widehat{\Theta}\right) &= \frac{\partial \ln L_t(\Theta)}{\partial \Theta}\Big|_{\theta=0} \\
&= \left[\,0\;0\;0\;0\;0\;\sum_{t=1}^{T}\left(\frac{r_{1,t}-\widehat{\mu}_1}{\widehat{\sigma}_1}\right)^2\left(\frac{r_{2,t}-\widehat{\mu}_2}{\widehat{\sigma}_2}\right)^2 - T\left(1+2\widehat{\rho}^2\right)\right]'. \qquad (26)
\end{aligned}
$$

The Lagrange multiplier statistic is obtained by substituting the expressions in Eqs. 24 and 26 into

$$
LM = q\left(\widehat{\Theta}\right)' I^{-1}\left(\widehat{\Theta}\right) q\left(\widehat{\Theta}\right). \qquad (27)
$$

The test statistic for contagion through the covolatility channel is

$$
LM = \left(\frac{\frac{1}{T}\sum_{t=1}^{T}\left(\frac{r_{1,t}-\widehat{\mu}_1}{\widehat{\sigma}_1}\right)^2\left(\frac{r_{2,t}-\widehat{\mu}_2}{\widehat{\sigma}_2}\right)^2 - \left(1+2\widehat{\rho}^2\right)}{\sqrt{\frac{(4\widehat{\rho}^4+16\widehat{\rho}^2+4)}{T}}}\right)^2, \qquad (28)
$$

which is denoted by CV in the paper.

Appendix C: Summary of Crisis Dating Assumptions in Selected Papers for the Period of 1997 to 2013

Table 9 Summary of crisis dating in papers written on the Asian financial crisis

Paper	Source	Non-crisis dates	Crisis dates	Notes
Forbes (2001)	TH	NS	Jun 30 97–Jul 6 97	Weekly
Dungey et al. (2002)	HK	Jan 1 95–Oct 19 97	Oct 20 97–Dec 31 97	
Gelos and Sahay (2001)	TH	Feb 4 97–Jul 1 97	Jul 2 97-Jan 29 98	
Forbes and Rigobon (2002)	HK	Jan 1 96–Oct 16 97	Oct 17 97–Nov 16 97	
Jang and Sul (2002)	ID,KR,TH	Oct 1 96–May 31 97	Jun 1 97–Jan 31 98	
Baur (2003)	TH	NS	Jul 2 97–Sep 2 97	
	HK		Oct 17 97–Nov 17 97	
Billio and Pelizzon (2003)	HK	Jan 1 96–May 31 97	Jun 1 97–Jan 31 98	
Kaminsky et al. (2003)	V	n.a.	Jul 2 97	Start date only specified
Rigobon (2003)	HK	Jan 2 97–Jun 2 97	Oct 27 97–Nov 28 97	Weekly
	KR		Dec 1 97–Jan 30 98	
	TH		Jun 10 97–Aug 29 97	
Caporale et al. (2005)	HK	Jan 90–Sep 97	Oct 97–Jul 98	Weekly
	TH	Jan 90–May 97	Jun 97–Jul 98	
Collins and Gavron (2005)	TH	Jul 1 96–Jul 1 97	Jul 2 97–Aug 1 97	
Serwa and Bohl (2005)	HK	Sep 1 97–Oct 22 97	Oct 23 97–Nov 22 97	
	KR	Sep 17 97–Dec 14 97	Dec 15 97–Jan 12 98	
Chiang et al. (2007)	HK	Jan 1 90–Oct 16 97	Oct 17 97–Mar 21 03	
	TH	Jan 1 90–Jul 1 97	Jul 2 97–Mar 21 03	
Baur and Fry (2009)	NS	Apr 30 97–May 1 97	May 2 97–May 29 98	
Laeven and Valencia (2008)	TH	NS	1997	Banking crisis

Table 9 (continued)

Paper	Source	Non-crisis dates	Crisis dates	Notes
Essaadi et al. (2009)	TH	Jan 96–Dec 97	Jul 2 97–Dec 31 98	
Fry et al. (2010)	HK	Jan 2 96–Oct 16 97	Oct 17 97–Jun 30 98	Real estate & equity
Kali and Reyes (2010)	TH	Jan 92–Dec 94	Jun 5 97-Jan 3 98	Weekly
Syllignakis and Kouretas (2011)	V	All non-crisis data	Nov 21 97–Oct 30 98	Weekly; Russian crisis
Briere et al. (2012)	V	All non-crisis data	Jul 2 97–Jan 13 98	Weekly equity & bond returns
Choe et al. (2012)	HK	Jan 1 96–Oct 16 97	Oct 17 97–Nov 14 97	
Kenourgios and Padhi (2012)	TH	All non-crisis data	Jan 1 97-Dec 31 97	Bond & equity returns

HK Hong Kong; *ID* Indonesia; *KR* Korea; *TH* Thailand; *NS* Not specified; *V* Various

Table 10 Summary of crisis dating in papers written on the Russian and LTCM crises

Paper	Source	Non-crisis dates	Crisis dates	Notes
Crisis: Russia				
Gelos and Sahay (2001)	RU	Jul 16 98-Oct 15 98	Jan 31 98-Jul 15 98	Currency & equity returns
Rigobon (2003)	RU	Mar 2 98-Jun 1 98	Aug 3 98-Aug 31 98	
Kaminsky et al. (2003)	RU	NS	Aug 18 98	Start date only specified
AuYong et al. (2004)	V	NS	Aug 17 98-Jan 12 99	Exchange rates
Collins and Gavron (2005)	RU	Aug 16 97-Aug 16 98	Aug 17 98-Sep 16 98	
Serwa and Bohl (2005)	RU	Jun 6 98-Aug 5 98	Aug 6 98-Oct 5 98	
DFGM (2007)	RU	Jan 5 98-Jul 31 98	Aug 3 98-Dec 31 98	
Sojli (2007)	RU	Jan 1 97-Jul 31 98	Aug 10 98-Aug 31 98	
Laeven and Valencia (2008)	RU	NS	Jan 1 98-Dec 31 98	Banking, currency & debt crises
Reinhart and Rogoff (2008b)	RU	NS	Jan 1 98-Dec 31 98	Banking crisis
Saleem (2009)	RU	Jan 1 95-Jul 31 98	Aug 1 98-Dec 31 98	
DFGM and Tang (2009)	RU	All non-crisis data	Aug 17 98-Dec 31 98	Bond & equity returns
Kali and Reyes (2010)	RU	Jan 92–Dec 94	May 23 98-Jan 16 99	Weekly
Syllignakis and Kouretas (2011)	V	All non-crisis data	Nov 21 97-Oct 30 98	Weekly; Asian crisis
Kenourgios and Padhi (2012)	CR	All non-crisis data	Jan 1 98-Dec 31 98	Bond & equity returns
Crisis: LTCM				
Rigobon (2003)	LTCM	Mar 2 98-Jun 1 98	Aug 31 98-Oct 15 98	
Kaminsky et al. (2003)	LTCM	NS	Sep 2 98	Start date only specified
Kabir and Hassan (2005)	DUM	Jun 6 98-Sep 1 98	Sep 2 98-Sep 17 98	3 periods analyzed
			Sep 18 98-Sep 24 98	
			Sep 25 98-Oct 14 98	
DFGM and Tang (2009)	US	All non-crisis data	Sep 23 98-Oct 15 98	Bond & equity returns
Briere et al. (2012)	V	All non-crisis data	Aug 17 98-Oct 15 98	Russian crisis; Weekly equity & bond returns

DUM dummy variable control for source; *CR* Czech Republic; *RU* Russia; *NS* Not specified; *V* Various; *DFGM* Dungey, Fry, Gonzalez-Hermosillo and Martin

Table 11 Summary of crisis dating in papers written on the Brazilian, dot-com and Argentinian crises

Paper	Source	Non-crisis dates	Crisis dates	Notes
Crisis: Brazil				
Baig and Goldfajn (2000)	RU	Jan 1 97-May 30 97	Jan 1 98-Jun 30 99	Equity & bond returns
Kaminsky et al. (2003)	BR	NS	Feb 1 99	Start date only specified
Rigobon (2003)	BR	Mar 2 98-Jun 1 98	Oct 15 98-Nov 23 98	
Collins and Gavron (2005)	BR	Jan 12 98-Jan 12 99	Jan 13 99-Feb 12 99	
Serwa and Bohl (2005)	BR	Nov 1 98-Dec 31 98	Jan 1 99-Mar 1 99	
Laeven and Valencia (2008)	BR	NS	Jan 1 99-Dec 31 99	Currency crisis
DFGM and Tang (2009)	BR	All non-crisis data	Jan 7 99-Feb 25 99	Bond & equity returns
AuYong et al. (2004)	V	NS	Jan 13 99-Dec 31 99	Exchange rates
Briere et al. (2012)	V	All non-crisis data	Jan 13 99-Jan 31 99	Weekly equity & bond returns
Crisis: dot-com				
Hon et al. (2007)	US	Mar 10 99-Mar 10 00	Mar 13 00-Mar 12 01	
DFGM and Tang (2009)	US	All non-crisis data	Feb 28 00-Jun 7 00	Bond & equity returns
Munoz et al. (2010)		Nov 22 97-Mar 9 00	Mar 10 00-Apr 9 00	
Syllignakis and Kouretas (2011)	V	All non-crisis data	Mar 10 00-Sep 27 02	Weekly
Crisis: Argentina				
Boschi (2005)	AR	Jan 1 01-May 31 01	Dec 1 01-Nov 29 02	
Collins and Gavron (2005)	AR	Jul 3 00-Jul 2 01	Jul 3 01-Aug 2 01	
Serwa and Bohl (2005)	AR	Oct 13 01-Dec 12 01	Dec 27 2001-Feb 26 2002	
Laeven and Valencia (2008)	AR	NS	2001	
Reinhart and Rogoff (2008b)	AR	NS	Jan 1 01-Dec 31 01	
DFGM and Tang (2009)	AR	All non-crisis data	Oct 11 01-Mar 3 05	
Kali and Reyes (2010)	AR	Jan 92–Dec 94	Jun 2 01-Apr 6 02	
Kenourgios and Padhi (2012)	AR	All non-crisis data	Jan 1 99-Dec 31 00	Bond & equity returns

AR Argentina; *BR* Brazil; *RU* Russia; *US* US; *NS* Not specified; *V* Various; *DFGM* Dungey, Fry, Gonzalez-Hermosillo and Martin

Table 12 Summary of crisis dating in papers written on the sub-prime crisis and the great recession

Paper	Source	Non-crisis dates	Crisis dates	Notes
Crisis: sub-prime				
Laeven and Valencia (2008)	US	NS	2007	
Reinhart and Rogoff (2008b)	US	NS	Jan 1 07-Dec 31 07	
DFGM and Tang (2009)	US	All non-crisis data	Jul 26 07-Dec 31 07	
Fry et al. (2010)	US	Jan 2 07-Jul 25 07	Jul 26 07-Dec 25 07	
Horta et al. (2010)	US	Jan 1 05-Jul 31 07	Aug 1 07-Apr 21 08	
Longstaff (2010)	CDO	Jan 1 06-Dec 31 06	Jan 1 07-Dec 31 07	
Munoz et al. (2010)	V	Apr 10 00-Aug 14 07	Aug 15 07-Sep 14 07	
Hatemi-J and Roca (2011)	US	Jan 1 05-Jul 31 07	Aug 1 07-Dec 31 09	Weekly real estate returns
Briere et al. (2012)	V	All non-crisis data	Feb 8 07-Mar 10 09	Weekly equity & bond returns
Gallegati (2012)	US	June 3 03-Jul 31 07	Aug 1 07-Dec 19 08	
Kenourgios and Padhi (2012)	US	All non-crisis data	Jul 1 07-Jul 31 08	
Samitas and Tsakalos (2013)	GR	Jan 2 05-Dec 31 07	Jan 2 08-Dec 31 09	
Crisis: great recession				
Kim et al. (2010)	CDO	Jan 05-Jul 07	Aug 07-Jan 09	
Longstaff (2010)	CDO	Jan 1 06-Dec 31 06	Jan 1 08-Dec 31 08	
Munoz et al. (2010)	V	Apr 10 00-Aug 14 07	Sep 15 08-Oct 14 08	
Naoui et al. (2010)	US	Jan 3 06-Jul 31 07	Aug 1 07-Feb 26 10	
Bekaert et al. (2011)	US	NS	Aug 7 07-Mar 15 09	Weekly
Chudik and Fratzscher (2011)	US	Jan 1 05-Aug 6 07	Aug 7 07-Jul 31 09	
Syllignakis and Kouretas (2011)	V	All non-crisis data	Sep 26 08-Feb 13 09	Weekly
Pais and Stork (2011)	AU	Jan 5 00-Apr 30 07	May 1 07-Feb 6 09	Banking equity & real estate
Arghyrou and Kontonikas (2012)	v	Jan 99-Jul 07	Aug 2007-Feb 10	Monthly bond returns

Table 12 (continued)

Paper	Source	Non-crisis dates	Crisis dates	Notes
Crisis: great recession				
Baur (2012)	V	NS	Jul 07-Mar 09	Weekly
Celik (2012)	US	Jan 3 05-Jul 16 07	Jul 17 07-Aug 31 09	Exchange rates
Metiu (2012)	V	NS	Jan 1 08-Feb 31 11	Bond returns
Kalbaska and Gatkowski (2012)	NS	NS	Jul 07-Sep 10	Bond returns
Wen et al. (2012)	V	Dec 30 05-Sep 14 08	Sep 15 08-Nov 30 10	Energy & equity returns
Hsiao (2012)	US	Apr 1 05-Jun 29 07	Mar 03 08-Aug 31 09	Equity & banking equity

CDO - asset backed collateralized debt obligation market; *AU* Australia; *GR* Greece; *NS* Not specified; *US* US; *V* Various; *DFGM* Dungey, Fry, Gonzalez-Hermosillo and Martin

Table 13 Summary of crisis dating in papers written on the European debt crisis

Paper	Source	Non-crisis dates	Crisis dates	Notes
Cocozza and Piselli (2011)	V	Jan 1 03-Jul 31 07	Aug 1 07-Mar 31 09	Weely
Lucas et al. (2011)	NS	NS	Jan 1, 08 - Jun 30 11	Bond returns, Great recession
Hui and Chung (2011)	NS	Jan 2 06-Aug 31 09	Sep 1 09-Apr 30 10	Option prices
Missio and Watzka (2011)	GR	NS	Dec 31 08-Dec 31 10	
Arghyrou and Kontonikas (2012)	V	Jan 99-Jul 07	Mar 10-Aug 11	Monthly bond returns
Fong and Wong (2012)	V	NS	Dec 14 07- Sep 30 11	Bond returns, Great recession
Mink and Haan (2013)	GR	NS	Jan 1, 10- Dec 31, 10	Bond returns
Samitas and Tsakalos (2013)	GR	Jan 2 05-Dec 31 07	Jan 1 10-Apr 14 11	

GR Greece; *NS* Not specified; *V* Various

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