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Abstract

We investigate the role of public, private, and external debt in explaining the propagation of financial shocks during three major financial crises from 2007-2013. For our analysis, we construct indices of crisis severity in equity markets based on different tests of contagion and investigate whether the transmission of crises across countries can be related to similar debt conditions. We compare the role of debt stocks and flows to traditional channels for contagion based on regional and trade linkages. Our main finding is that, along with regional linkages, public and external debt play a more important role than trade linkages in driving contagion across equity markets.

Keywords: Contagion; debt; European debt crisis; financial crisis; Great Recession, trade linkages; regional linkages
JEL Classifications: C51;G01;G15

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1 Introduction

Recent financial crises have renewed interest in financial market contagion and its sources. Contagion can be described as a trigger country suffering a negative shock that quickly spreads to other countries through numerous real and financial channels. Influential methods for measuring contagion include the adjusted correlation tests of Forbes and Rigobon (2002), the outlier tests of Favero and Giavazzi (2002), the threshold tests of Pesaran and Pick (2007), the latent factor approach of Dungey and Martin (2007), the co-skewness analysis of Fry et al. (2010), and the co-kurtosis and co-volatility tests of Fry-McKibbin and Hsiao (2014).

In this paper, we investigate how crises in equity markets spread across countries during the three episodes of the subprime mortgage crisis, the Great Recession, and the European sovereign debt crisis. Several indices of crisis severity are constructed based on the six tests of contagion developed by Fry et al. (2010) and Fry-McKibbin and Hsiao (2014) to gauge how vulnerable countries are to financial crises through a particular channel. Unlike in most other studies that assign a crisis date (Forbes and Rigobon, 2002), the crisis severity indices are allowed to vary over the period of crisis. Thus, the peak level of crisis severity will be determined through the correlation and higher order channels at a specific date.[1]

A key question of interest in this paper is whether countries with weaker fundamentals are more likely to experience a crisis due to contagion. Several channels of contagion have been explored previously in the literature, including through the links arising from trade (Van Rijckeghem and Weder, 2001; and Kali and Reyes, 2010), regional proximity to the source market (Glick and Rose, 1999), development comparability (Fry-McKibbin et al., 2013), external and internal imbalances (Caramazza et al., 2004; Ehrmann et al. 2009; and Bekaert et al., 2011), internal and external debts (Reinhart and Rogoff, 2011; and Forbes, 2012), finance (Ahlgren and Antell, 2010), and both macro and finance (Morley, 2013).

Although many studies focus on analyzing the relationship between the spread of crises and macroeconomic fundamentals, this paper contributes to the literature in three important ways. First, we consider a broader set of fiscal fundamentals in explaining the transmission of crisis. The recent European sovereign debt crisis in

[1]It should be noted that some studies have developed regime switching models for measuring market contagion to deal with the dating issue of the crisis period (Billio and Caporin, 2005; Pelletier, 2006; Chan et al., 2013; and Kasch and Caporin, 2013).

particular is characterized by a serious deterioration of fiscal conditions such as high levels of public (as well as private and external) debt, as well as fiscal and current account deficits. Using a sample of 44 countries, we investigate empirically the relevance of domestic and external weaknesses, including fiscal conditions, as well as trade and regional linkages in explaining the transmission of crises, especially for the European debt crisis. Several indicators in each year prior to a crisis are analyzed to examine whether the incidence of crisis for the countries with weak market fundamentals differs significantly from the countries with sound fundamentals.

Second, we make use of high-frequency data to study the early warning indicators of financial instability with a focus on fiscal and macro fundamentals. In this case, the crisis severity for countries with weak or sound fiscal conditions can be calculated over the period of financial crises. Unlike most of papers in the literature using low-frequency data to study the role of fiscal and macro fundamentals (Bekaert et al., 2011; and Giordano et al., 2013), our approach of using high-frequency data allows us to identify the peak level of crisis severity at a specific date. Although Fry-McKibbin et al. (2013) study high-frequency data to explore a range of channels, they focus on trade and financial linkages, but not fiscal conditions. Here, we analyze the indicators of public, private, and external debts, as well as domestic and external imbalances, which have mostly been ignored by previous studies, in explaining the propagation of financial shocks during three crises from 2007-13.

Third, several indices of crisis severity are constructed based on the six tests of contagion developed by Fry et al. (2010) and Fry-McKibbin and Hsiao (2014) in which the transmission channels of financial shocks can be identified jointly through the correlation and higher order co-moments. Recent global financial crises have reminded investors that asset returns are driven by asymmetric and fat-tailed distributions, suggesting that both the correlation and the higher order co-moments need to be considered for measuring financial contagion.[2] The proposed indices of crisis severity enable us to capture changes in various aspects of asset return relationships such as cross-market mean and mean (i.e., correlation), cross-market mean and volatility (co-skewness), cross-market mean and skewness (co-kurtosis), as well as cross-market

[2]Multiple-channel tests of contagion are studied by Chan et al. (2013) and Fry-McKibbin et al. (2013) in which the propagation mechanism of financial shocks across international financial markets are identified jointly through the correlation and higher order co-moments. Fry-McKibbin et al. (2013) show that the joint tests of contagion have the advantage over the existing single-channel tests of contagion in the literature in that they yield the correct size in small samples.

volatilities (co-volatility).

Our results indicate that the European sovereign debt crisis was the most pervasive crisis of the three recent crises, as it affected equity markets not only through the correlation channel but also higher order channels, supporting the idea that both linear and non-linear market dependence can be important in measuring financial contagion. Particularly, the correlation channel was the most dominant, followed by the co-kurtosis and co-volatility channels, with the co-skewness channels the least important. For all three crises, fiscal conditions and regional linkages play a significant role in explaining the transmission of crises, especially for the European debt crisis, while the trade linkages do not necessarily accelerate changes in crisis transmission. Public debt and the fiscal balance can be treated as the early warning indicators for the European debt crisis, but not for the subprime crisis and the Great Recession; however, the private and external debts, as well as the both fiscal and current account balances, can be treated as major warning indicators for all three crises. Perhaps not surprisingly, the crisis that is mainly regional in focus is the European debt crisis, which transmitted the financial shocks across Europe through the correlation and co-skewness channels.

The rest of this paper proceeds as follows. Section 2 reviews the six types of contagion tests used for constructing the indices of crisis severity. Section 3 describes the three episodes of crisis and data used in the paper. Fiscal and macro variables are considered to help explore whether these indicators explain the transmission of crisis. The empirical results are presented in Section 4, with the concluding comments given in Section 5.

2 Contagion Tests and Crisis Severity

Six types of contagion tests are introduced in this section to help develop several crisis severity indices. The six tests are documented in detail in Fry et al. (2010) and Fry-McKibbin and Hsiao (2014), and are briefly summarized here. The statistical tests are derived in Fry et al. (2010) and Fry-McKibbin and Hsiao (2014) from a family of bivariate distributions based on the generalized exponential distribution of Cobb et al. (1983) and Lye and Martin (1993). In that framework, the bivariate normal distribution is extended to allow for dependence structures through higher order co-moments, with Lagrange multiplier tests derived as the basis of tests for contagion.

The first test of contagion is a correlation based test similar to that used in Forbes

and Rigobon (2002) and refined in Fry et al. (2010), which tests for changes in correlations across different sample periods. The second and third tests identify contagion as a significant change in (two alternative forms of) co-skewness across markets during periods of financial market instability compared to normal times. The fourth to sixth tests of contagion developed by Fry-McKibbin and Hsiao (2014) are based on a significant change in (two alternative forms of) co-kurtosis or co-volatility across markets during the crisis period compared to the non-crisis period. The identification of contagion using each of these tests rests partly on the specification of a crisis source asset market denoted by i, while j represents the recipient market.

2.1 Correlation Contagion Test

The correlation test presented here is slightly different to that of Forbes and Rigobon (2002) as the data period is non-overlapping (Fry et al., 2010). The statistic for contagion (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 $\left(\widehat{\rho}_x\right)$ from source market i to recipient j can be represented as[3]

$$CR(i \rightarrow j) = \left(\frac{\widehat{\nu}_{y|x_i} - \widehat{\rho}_x}{\sqrt{Var\left(\widehat{\nu}_{y|x_i} - \widehat{\rho}_x\right)}} \right)^2, \tag{1}$$

Correlation coefficients may be biased upwards because of increased volatility in asset returns in the source market during financial market crises. Forbes and Rigobon (2002) show how this bias can be removed using

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

[3]The standard error in equation (1) is presented in Fry et al. (2010), where

$$\begin{aligned}
Var\left(\widehat{\nu}_{y|x_i} - \widehat{\rho}_x\right) &= Var\left(\widehat{\nu}_{y|x_i}\right) + Var\left(\widehat{\rho}_x\right) - 2Cov\left(\widehat{\nu}_{y|x_i}, \widehat{\rho}_x\right) \\
Var\left(\widehat{\nu}_{y|x_i}\right) &= \frac{1}{2}\frac{(1+\delta)^2}{\left[1+\delta\left(1-\rho_y^2\right)\right]^3}\left[\frac{1}{T_y}\left(\left(2-\rho_y^2\right)\left(1-\rho_y^2\right)^2\right) + \frac{1}{T_x}\left(\rho_y^2\left(1-\rho_y^2\right)^2\right)\right] \\
Var\left(\widehat{\rho}_x\right) &= \frac{1}{T_x}\left(1-\rho_x^2\right)^2 \\
Cov\left(\widehat{\nu}_{y|x_i}, \widehat{\rho}_x\right) &= \frac{1}{2}\frac{1}{T_x}\frac{\rho_y\rho_x\left(1-\rho_y^2\right)\left(1-\rho_x^2\right)(1+\delta)}{\sqrt{\left[1+\delta\left(1-\rho_y^2\right)\right]^3}}.
\end{aligned}$$

which adjusts the unconditional correlation coefficient $\left(\widehat{\rho}_y\right)$ of the crisis period between the source and recipient countries for heteroskedasticity. The denominator of the conditional correlation coefficient $\left(\widehat{\nu}_{y|x_i}\right)$ includes a term $\delta = (s^2_{y,i} - s^2_{x,i})/s^2_{x,i}$ which 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.

2.2 Co-skewness Contagion Tests

The co-skewness contagion tests take two forms. The first form of co-skewness test of contagion is denoted CS_1. It is identified 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 co-skewness coefficient $\left(\widehat{\psi}_x\right)$ compared to the crisis period co-skewness coefficient $\left(\widehat{\psi}_y\right)$. This type of test statistic is given by

$$CS_1\left(i \to j; r_i^1, r_j^2\right) = \left(\frac{\widehat{\psi}_y\left(r_i^1, r_j^2\right) - \widehat{\psi}_x\left(r_i^1, r_j^2\right)}{\sqrt{\dfrac{4\widehat{\nu}^2_{y|x_i} + 2}{T_y} + \dfrac{4\widehat{\rho}^2_x + 2}{T_x}}} \right)^2, \tag{3}$$

where the co-skewness statistics are

$$\widehat{\psi}_y\left(r_i^a, r_j^b\right) = \frac{1}{T_y}\sum_{t=1}^{T_y}\left(\frac{y_{i,t} - \widehat{\mu}_{y_i}}{\widehat{\sigma}_{y_i}}\right)^a\left(\frac{y_{j,t} - \widehat{\mu}_{y_j}}{\widehat{\sigma}_{y_j}}\right)^b, \tag{4}$$

$$\widehat{\psi}_x\left(r_i^a, r_j^b\right) = \frac{1}{T_x}\sum_{t=1}^{T_x}\left(\frac{x_{i,t} - \widehat{\mu}_{x_i}}{\widehat{\sigma}_{x_i}}\right)^a\left(\frac{x_{j,t} - \widehat{\mu}_{x_j}}{\widehat{\sigma}_{x_j}}\right)^b, \tag{5}$$

The terms $\mu_{y_i}, \mu_{y_j}, \mu_{x_i}, \mu_{x_j}$ are the mean of the equity returns of market i and j 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.

The second version of the co-skewness contagion test statistic is denoted CS_2. The test statistic is given by

$$CS_2\left(i \to j; r_i^2, r_j^1\right) = \left(\frac{\widehat{\psi}_y\left(r_i^2, r_j^1\right) - \widehat{\psi}_x\left(r_i^2, r_j^1\right)}{\sqrt{\dfrac{4\widehat{\nu}^2_{y|x_i} + 2}{T_y} + \dfrac{4\widehat{\rho}^2_x + 2}{T_x}}} \right)^2, \tag{6}$$

The CS_2 $(i \rightarrow j; r_i^2, r_j^1)$ is a test for contagion through new spillover 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.

2.3 Co-volatility and Co-kurtosis Contagion Tests

The co-volatility contagion test statistic is denoted CV, gives

$$CV\left(i \rightarrow j; r_i^2, r_j^2\right) = \left(\frac{\widehat{\psi}_y\left(r_i^2, r_j^2\right) - \widehat{\psi}_x\left(r_i^2, r_j^2\right)}{\sqrt{\frac{4\widehat{\nu}_{y|x_i}^4 + 16\widehat{\nu}_{y|x_i}^2 + 4}{T_y} + \frac{4\widehat{\rho}_x^4 + 16\widehat{\rho}_x^2 + 4}{T_x}}} \right)^2, \tag{7}$$

where

$$\begin{aligned}
\widehat{\psi}_y\left(r_i^2, r_j^2\right) &= \frac{1}{T_y}\sum_{t=1}^{T_y}\left(\frac{y_{i,t} - \widehat{\mu}_{y_i}}{\widehat{\sigma}_{y_i}}\right)^2\left(\frac{y_{j,t} - \widehat{\mu}_{y_j}}{\widehat{\sigma}_{y_j}}\right)^2 - (1 + 2\widehat{\nu}_{y|x_i}^2), \\
\widehat{\psi}_x\left(r_i^2, r_j^2\right) &= \frac{1}{T_x}\sum_{t=1}^{T_x}\left(\frac{x_{i,t} - \widehat{\mu}_{x_i}}{\widehat{\sigma}_{x_i}}\right)^2\left(\frac{x_{j,t} - \widehat{\mu}_{x_j}}{\widehat{\sigma}_{x_j}}\right)^2 - (1 + 2\widehat{\rho}_x^2),
\end{aligned}$$

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

Co-kurtosis contagion tests take two forms. The first form of co-kurtosis contagion test is denoted CK_1. This test of the transmission of contagion $(i \rightarrow j; r_i^1, r_j^3)$ is identified from the mean $(a = 1)$ of asset i to the skewness $(b = 3)$ of j through changes in the non-crisis co-kurtosis coefficient $\left(\widehat{\psi}_x\right)$ compared to the crisis period co-kurtosis coefficient $\left(\widehat{\psi}_y\right)$. The test statistic for CK_1 is given by

$$CK_1\left(i \rightarrow j; r_i^1, r_j^3\right) = \left(\frac{\widehat{\xi}_y\left(r_i^1, r_j^3\right) - \widehat{\xi}_x\left(r_i^1, r_j^3\right)}{\sqrt{\frac{18\widehat{\nu}_{y|x_i}^2 + 6}{T_y} + \frac{18\widehat{\rho}_x^2 + 6}{T_x}}} \right)^2. \tag{8}$$

where

$$\widehat{\xi}_y\left(r_i^a, r_j^b\right) = \frac{1}{T_y}\sum_{t=1}^{T_y}\left(\frac{y_{i,t} - \widehat{\mu}_{yi}}{\widehat{\sigma}_{yi}}\right)^a\left(\frac{y_{j,t} - \widehat{\mu}_{yj}}{\widehat{\sigma}_{yj}}\right)^b - 3\widehat{v}_{y|x_i}, \tag{9}$$

$$\widehat{\xi}_x\left(r_i^a, r_j^b\right) = \frac{1}{T_x}\sum_{t=1}^{T_x}\left(\frac{x_{i,t} - \widehat{\mu}_{xi}}{\widehat{\sigma}_{xi}}\right)^a\left(\frac{x_{j,t} - \widehat{\mu}_{xj}}{\widehat{\sigma}_{xj}}\right)^b - 3\widehat{\rho}_x. \tag{10}$$

The second version of the co-kurtosis contagion test statistic is denoted CK_2, gives

$$CK_2\left(i \rightarrow j; r_i^3, r_j^1\right) = \left(\frac{\widehat{\xi}_y\left(r_i^3, r_j^1\right) - \widehat{\xi}_x\left(r_i^3, r_j^1\right)}{\sqrt{\frac{18\widehat{\nu}_{y|x_i}^2 + 6}{T_y} + \frac{18\widehat{\rho}_x^2 + 6}{T_x}}} \right)^2, \tag{11}$$

The $CK_2\left(i \rightarrow j; r_i^3, r_j^1\right)$ is a test for contagion through new spillover from the skewness ($a = 3$) of the equity returns of the crisis market to the mean ($b = 1$) of the equity market returns of the recipient country.

2.4 Hypotheses of Contagion

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

$$\begin{aligned} H_0 &: \nu_{y|x_i} = \rho_x, \\ H_1 &: \nu_{y|x_i} \neq \rho_x, \end{aligned}$$

for the correlation channel, and

$$\begin{aligned} H_0 &: \psi_y\left(r_i^a, r_j^b\right) = \psi_x\left(r_i^a, r_j^b\right), \\ H_1 &: \psi_y\left(r_i^a, r_j^b\right) \neq \psi_x\left(r_i^a, r_j^b\right), \end{aligned}$$

for the co-skewness ($a = 1, b = 2$; and $a = 2, b = 1$), and co-volatility ($a = b = 2$), and

$$\begin{aligned} H_0 &: \xi_y\left(r_i^a, r_j^b\right) = \xi_x\left(r_i^a, r_j^b\right), \\ H_1 &: \xi_y\left(r_i^a, r_j^b\right) \neq \xi_x\left(r_i^a, r_j^b\right), \end{aligned}$$

for the co-kurtosis ($a = 1, b = 3$; and $a = 3, b = 1$) channels. Under the null hypothesis of no contagion, the correlation (CR), co-skewness (CS_1 and CS_2), co-volatility (CV), and co-kurtosis (CK_1 and CK_2) are each asymptotically distributed as χ_1^2.

2.5 Measure of Crisis Severity

The indices of crisis severity are constructed by using the above six tests of contagion through the correlation, co-skewness, co-volatility, and co-kurtosis channels. An indicator variable is constructed for each recipient country j, which takes a value of 1 if

the test statistic is significant at the 0.05 level of significance. Here for the correlation test as an example,

$$I_{CR,j} = \begin{cases} 1: & \text{p-value} \leq 0.05 \\ 0: & \text{otherwise} \end{cases}, \tag{12}$$

The index of crisis severity using the correlation test (S_{CR}) is

$$S_{CR}(i \rightarrow j) = 100. \left(\frac{\sum_{j=1}^{J} I_{CR,j}}{J} \right), \ i \neq j, \tag{13}$$

where J is the total number of the receipt market. The other five indices of crisis severity are in the similar form as the equation (13) except for the indicator variable based on the correlation test (I_{CR}) is replaced to the indicator variable for a particular test.

Two types of overall indices of crisis severity are introduced here. The first type of the overall index $S_{Total_1}(i \rightarrow j)$ is constructed based on three types of contagion tests of correlation and two forms of co-skewness

$$S_{Total_1}(i \rightarrow j) = 100. \left(\frac{\sum_{j=1}^{J} (I_{CR,j} + I_{CS_1,j} + I_{CS_2,j})}{3J} \right), \ i \neq j, \tag{14}$$

where I_{CR}, I_{CS_1} and I_{CS_2} are the indicator variables based on the correlation test and two forms of co-skewness tests, respectively.

The second type of the overall index $S_{Total_2}(i \rightarrow j)$ is constructed based on six types of contagion tests (correlation, two forms of co-skewness, co-volatility, and two forms of co-kurtosis)

$$S_{Total_2}(i \rightarrow j) = 100. \left(\frac{\sum_{j=1}^{J} (I_{CR,j} + I_{CS_1,j} + I_{CS_2,j} + I_{CV,j} + I_{CK_1,j} + I_{CK_2,j})}{6J} \right), \ i \neq j, \tag{15}$$

where I_{CV}, I_{CK_1} and I_{CK_2} are the indicator variables for the co-volatility and co-kurtosis tests, respectively.

3 Possible Explanations for the Transmission of Crises

This section discusses the data used for our empirical analysis of the three episodes of crisis. In order to study the transmission of crisis through links arising from fiscal conditions, trade, and regional proximity, a variety of fiscal and macroeconomic variables are analyzed to explain whether the incidence of crisis severity differs significantly between countries with weak fiscal positions and the rest of the countries in the sample.

3.1 Three Episodes of Crisis

The sample consists of daily equity price indices ($P_{k,t}$) expressed in US dollars collected for the $k = 44$ equity markets. The countries are classified into four regions of Asia, Latin America, Europe and "other" for the empirical analysis. The 11 countries grouped in the Asian region are China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan and Thailand. The 22 countries grouped in the European region are Austria, Belgium, Bulgaria, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Russia, Spain, Sweden, Switzerland, Turkey and the UK. The 6 countries grouped in the Latin American region are Argentina, Brazil, Chile, Colombia, Mexico and Peru. The 5 countries selected in the "other" region are Australia, Canada, New Zealand, South Africa and the US.

Daily percentage equity returns ($R_{k,t}$) of the k^{th} market are calculated as

$$R_{k,t} = 100\left(ln(P_{k,t}) - ln(P_{k,t-1})\right), \tag{16}$$

Equation (16) is estimated to extract the data z_t as the net of interdependencies for the k markets through the effects of $\phi(L)$ in a VAR of the form

$$R_t = \phi(L) R_t + z_t$$

where $\phi(L)$ are parameter vectors of 5 lags ($L = 5$) and z_t is the vector of residuals which are used as the returns in the calculation of the contagion test statistics in equation (1) for the correlation channel, equations (3) and (6) for the co-skewness channels, equation (7) for the co-volatility channel, and equations (8) and (11) for the co-kurtosis channels. The data is adjusted by using average two-day returns to control for time zone effects (Forbes and Rigobon, 2002). The sample size is $T = 2,346$ and the effective sample period is 12 January 2005 to 31 December 2013.

The three crises considered are the subprime crisis, the Great Recession and the European sovereign debt crisis. These three crises could be thought of as one event and they could be difficult in separating the phases. The subprime mortgage crisis and the Great Recession are separated by the severity of the collapse of Lehman Brothers in September of 2008. The start date of the subprime crisis coincides with heightened risk aversion and falls in liquidity from July 26, 2007 ($T_{1,y} = 297$) (Fry et al., 2010). The Great Recession is defined to span from September 15, 2008 to December 31, 2009 ($T_{2,y} = 339$) days. The start date of the European debt crisis is chosen from January

Table 1:
Crisis and non-crisis period dates.

Non-crisis and crisis periods	Start of period	End of period	Obs.
The non-crisis period dates (x_t)	12 Jan 2005	25 Jul 2007	661
The crisis period dates			
Subprime mortgage ($y_{1,t}$)	26 Jul 2007	14 Sep 2008	297
Great recession ($y_{2,t}$)	15 Sep 2008	31 Dec 2009	339
European sovereign debt ($y_{3,t}$)	1 Jan 2010	31 Dec 2013	1044

1, 2010 to December 31, 2013 ($T_{3,y} = 1044$) days. The non-crisis period before these crises is from January 12, 2005 to July 25, 2007 ($T_x = 661$) days. Table 1 summarizes the dates chosen for each crisis episode and non-crisis period.

3.2 Characteristics of the Macroeconomic Variables

Several economic variables are considered to allow us to investigate whether these indicators provide an early indication of vulnerability to the three episodes of crisis mentioned above. The countries with worse economic conditions may be more vulnerable to crises than others. This paper focuses on identifying various economic variables in the year prior to a crisis in order to examine whether the incidence of crisis severity differs significantly between the countries with weak fiscal and macro conditions, and the rest of the countries in the sample. Bekaert et al. (2011) find that the portfolios in countries with weak economic fundamentals experience more contagion. Beirne and Fratzscher (2013) study the drivers of sovereign risk and find a link between a deterioration in countries' fundamentals and contagion.

The economic variables for 44 countries considered in this paper are the gross public debt, domestic private credit, external debt, the fiscal account balance, the current account balance, both account balances, and the value of trade.[4] These variables except for the value of trade are expressed as a percentage of GDP. The selected 44 countries are grouped into five categories by percentiles for each macroeconomic variable. Taking the variable for the debt to GDP ratio as an example, the debt to GDP ratio is in the 20^{th} percentile (very low debt level); the debt to GDP ratio is in the 40^{th} percentile (low debt level); the debt to GDP ratio is in the 60^{th} percentile

[4]Gross public debt is used instead of net public debt because net debt data are not available for a range of countries.

(medium debt level); and the debt to GDP ratio is in the 80^{th} percentile (high debt level). We define the countries with the worst deteriorative fiscal conditions based on a threshold of 80^{th} percentile of the distribution of the macroeconomic variable. If a country's debt measured as a percentage of GDP is above this percentile, this country will be classified in the high-debt group.

3.2.1 Public, Private, and External Debt

Table 2 consists of three panels, presenting the gross public debt, domestic credit, and external debt for the high-debt group of countries in the year preceding each crisis. The countries are selected based on a threshold of the 80^{th} percentile of the distribution for the debt level relative to GDP. In Table 2, panel A shows that if fiscal weakness, proxied by the gross public debt to GDP ratio, is selected as a facilitator of contagion, then Japan, Greece, Italy and Belgium will be more affected by contagion than the rest of the countries in the sample during the subprime crisis. For the Great Recession, Japan, Greece, and Italy are the countries in the sample that should be more affected by contagion if public debt is selected as a facilitator of contagion. For the European sovereign debt crisis, it is Japan, Italy, and Singapore which are expected to be more affected by contagion than other countries. The ratio of the public debt to GDP at the 80^{th} percentile is around 90% each year prior to the three episodes of crisis, which is the same ratio suggested by Reinhart and Rogoff (2010).[5]

Credit to private debt is one of the major macroeconomic variables that reflects the state of health of the financial system for a country. If bank lending has expanded rapidly, particularly for consumer loans, this could lead to an increase in credit risk and eventually to a banking crisis (Reinhart and Rogoff, 2011). Panel B of Table 2 illustrates that the countries selected to be in the high-debt group in 2006 are Poland, Canada, Japan, Denmark, Ireland, the UK, Netherlands, Spain, Switzerland, and South Africa and these countries are expected to be more exposed to contagion risk than the rest of countries in the sample during the subprime crisis. For the Great Recession, it is Poland, Denmark, Ireland, Netherlands, Spain, the UK, and Japan which are expected to be much more affected by contagion than the rest of countries. As for the European debt crisis, it is Poland, Ireland, Denmark, Netherlands, Spain, the UK, and the US that are expected to be affected by contagion. The selected countries are

[5]Reinhart and Rogoff (2010) find that 90% ratio of public debt to GDP is the point at which economic growth slows.

classified as a high-debt group as their domestic credit relative to GDP is above 286% in 2006, 292% in 2007, and 196% in 2009, respectively.

If a country has accumulated large amounts of foreign currency-denominated debt that exceeds a certain level, then the probability of default will increase substantially in a period of financial turbulence, making investors demand higher returns in compensation for the higher risk (Masson, 1999). Briguglio et al. (2009) find that a high level of external debt may make it more difficult to mobilize resources to offset the effects of external shocks. Panel C of Table 2 reveals that Ireland, the UK, and Netherlands are expected to have more contagion risk than other countries in the sample during the subprime crisis if the external debt is selected as a facilitator of contagion. For the Great Recession, it is Ireland, the UK, Netherlands, Switzerland, Hong Kong, and Belgium that should be more affected by contagion. For the European debt crisis, it is the Ireland, the UK, and Hong Kong which are likely to be affected by contagion. The threshold at the 80^{th} percentile for the high-debt countries measured by the ratio of external debt to GDP is 116% in 2006, 196% in 2007, and 320% in 2009, respectively.

3.2.2 Fiscal and Current Account Deficits

The fiscal and current account deficits are major important indicators in explaining the transmission of crisis. It is expected that if a country has either a larger fiscal deficit or current account deficit, the probability of risk for a country suffering from a crisis remains high. Edward (2006) and Rose and Spiegel (2012) find that countries with current account surpluses were better insulated from crisis. Manasse and Zavalloni (2013) find that the fiscal deficit significantly affect the sensitivity of the sovereign spread change to global risk. Burnside (2004) suggests the government can face substantial fiscal costs if significant contingent liabilities are realized and further the large fiscal costs can lead to crises.

Table 3 presents the fiscal deficit, current account deficit, and twin deficits as a percent of GDP for the high-deficit group of countries in the year prior to each crisis. If the fiscal balance is selected as a key transmission channel of contagion, then Greece, India, and Hungary will be more affected by contagion during the subprime mortgage crisis and the Great Recession. As for the European debt crisis, it is Spain, the UK, the US, and Ireland that will be more likely to be affected by contagion in comparison to the rest of the countries in the sample. The table shows that the threshold of fiscal deficit to GDP ratio for the high-deficit group is 6.02% in 2006, 4.41% in 2007, and

11.19% in 2009, respectively.

Panel B of Table 3 demonstrates that Romania, Portugal, Greece, and Bulgaria will be expected to have more contagion effects than the rest of the countries in the sample during the subprime mortgage crisis if the current account deficit is selected as a facilitator of contagion. As for the Great Recession, it is Spain, Portugal, Romania, Greece, and Bulgaria that are expected to be more exposed to contagion risks than the rest of countries. However, for the European debt crisis, only two markets, Bulgaria and Portugal, are expected to have more contagion from Greece than the rest of the countries. The threshold of the current account deficit for the high-deficit group of countries is around 10% each year prior to the three episodes of crisis.

Panel C of Table 3 reveals that if the twin deficits are selected as a facilitator of contagion, then Poland, Romania, Bulgaria, Portugal, Hungary, and Greece are the countries in the sample that should be more affected by contagion during the subprime crisis. For the Great Recession, it is the above European countries except for Poland and Hungary, which are expected to be more affected by a crisis than the rest of the countries. For the European debt crisis, it is Ireland and Portugal that are expected to be more affected by contagion. The threshold of the twin deficits as a percentage of GDP for the high-deficit group is 7% in 2006, 13% in 2007, and 16% in 2009, respectively.

3.2.3 Trade and Region

Trade is an important determinant of financial market integration. If a country trades intensively with the country in which a crisis originates, then it will be more likely to be affected by the crisis. The role of trade linkages in explaining financial market contagion has been studied by Eichengreen et al. (1996), Van Rijckeghem and Weder (2001) and de Haas and van Horen (2013).

Table 4 presents the largest trading partners of the source crisis countries in the year prior to their crisis. The largest trading partners are selected based on the distribution of the ratio of total trade using a threshold of the 80^{th} percentile. The US's major trading partners in 2006 are Canada, China, Mexico, Japan, Germany, the UK, and Korea, with these countries representing US$1,758.31 billion in exports and imports for the US, which is around 60% of trade for the US. If trade linkages are a facilitator of contagion, then these seven countries are expected to be more affected by contagion than the remaining 36 countries during the subprime crisis. During the Great Reces-

sion, the most likely countries in the sample to be affected by contagion are the above seven countries and France (around 60% of trade for the US). Greece is selected as the source market during the European debt crisis and its largest trading partners in 2009 are Germany, Italy, France, Russia, Netherlands, China, Korea, and the UK, covering around 50% of its trade. It is expected that these eight countries have more contagion risks than the rest of countries in the sample during the European debt crisis if the transmission channel of contagion is through trade linkages.

Contagion can be found to be a regional phenomenon when there is a crisis in the region, the neighboring countries are naturally more exposed to contagion risk than other countries (Glick and Rose, 1999; Caramazza et al., 2004; and Dungey et al., 2009). If the regional linkage is identified to render a country vulnerable to contagion, it is expected that the countries in Latin America are more affected by the subprime crisis and the Great Recession, as the crisis is in the US. The countries in the European region are much more exposed to contagion risk than those in other regions during the European sovereign debt crisis.

Table 2:
Gross government debt, domestic private credit, and external debt for the high-debt group of countries in the year prior to each crisis, expressed as a percentage of GDP. If a country's debt measured as a percentage of GDP is above the 80^{th} percentile, this country will be classified in the high-debt group. The data for gross government debt to GDP ratio is collected from IMF, World Economic Outlook Database. The data for domestic credit to GDP ratio and external debt to GDP ratio is collected from Datastream.

	2006		2007		2009	
	Country	% of GDP	Country	% of GDP	Country	% of GDP
(A)Government debt	Japan	186.00	Japan	183.01	Japan	210.25
	Greece	107.47	Greece	107.23	Italy	116.42
	Italy	106.35	Italy	103.28	Singapore	101.49
	Belgium	87.95				
(B)Domestic private credit	Poland	196.22	Poland	269.10	Poland	433.57
	Canada	194.19	Denmark	202.50	Ireland	232.10
	Japan	188.69	Ireland	199.17	Denmark	223.87
	Denmark	185.68	Netherlands	188.06	Netherlands	214.15
	Ireland	181.20	Spain	187.89	Spain	212.35
	UK	168.10	UK	184.29	UK	210.28
	Netherlands	167.19	Japan	181.12	US	196.33
	Spain	166.98				
	Switzerland	163.69				
	S Africa	163.37				
(C)External debt	Ireland	696.70	Ireland	785.25	Ireland	1107.06
	UK	329.38	UK	355.71	UK	398.20
	Netherlands	286.69	Netherlands	306.41	Hong Kong	320.56
			Switzerland	303.50		
			Hong Kong	299.59		
			Belgium	292.12		

Table 3:
Fiscal deficit, current account deficit and twin deficits for the high-deficit group of countries in the year prior to each crisis, expressed as percentage of GDP. If a country's account balance measured as a percentage of GDP is below the 20^{th} percentile, this country will be classified in the high-deficit group. The data is collected from IMF, World Economic Outlook Database. Twin deficits consists of fiscal and current account deficits.

	2006		2007		2009	
	Country	% of GDP	Country	% of GDP	Country	% of GDP
(A)Fiscal deficit	Greece	6.02	India	4.41	Spain	11.19
	India	6.17	Hungary	5.08	UK	11.25
	Hungary	9.37	Greece	6.76	US	12.93
					Ireland	13.78
(B)Current account deficit	Romania	10.39	Spain	10.00	Bulgaria	8.93
	Portugal	10.69	Portugal	10.10	Portugal	10.92
	Greece	11.39	Romania	13.43		
	Bulgaria	17.56	Greece	14.61		
			Bulgaria	25.20		
(c)Twin deficits	Poland	7.48	Portugal	13.31	Ireland	16.10
	Romania	11.74	Romania	16.54	Portugal	21.09
	Bulgaria	14.22	Greece	21.37		
	Portugal	14.44	Bulgaria	21.95		
	Hungary	16.77				
	Greece	17.41				

3.3 Evaluating Contagion Channels

The range of contagion channels considered are through links arising from debt stocks and flows, trade, and regional proximity. To explore the hypotheses for each channel listed above, crisis severity indices are computed based on the groups of countries identified in each case. Here, two groups of countries are examined in each case (i.e., the countries with the worst fiscal conditions versus the remaining countries in the sample, major trading partners versus the remaining countries in the sample, and regional countries versus countries outside of the region).

Two methods are used to compute the crisis severity indices. First, a simple analysis of the test statistics shown in Section 2 is conducted for each channel of contagion calculated over the crisis period from the source country to the recipient countries. Second, three types of crisis severity indices described in equations (13) to (15) are calculated by taking the non-crisis (x_t) period as fixed, the correlation, co-skewness, co-volatility, and co-kurtosis tests of contagion are calculated using a rolling 30-day window of returns through the crisis periods.

The indices of crisis severity described in section 2.5 are measured based on the total number of the receipt market ($J = 43$). Similar indices are constructed for each subgroup. Taking the crisis severity using the correlation test as an example. The crisis severity index for the high-debt group of countries (S_{CR}^{high}) is

$$S_{CR}^{high}(i \rightarrow j) = 100. \left(\frac{\sum_{j=1}^{N} I_{CR,j}}{N} \right), \; j = \text{high-debt } N \text{ countries}, \tag{17}$$

where N is the number of countries in the high-debt group. The crisis severity index for a rest of the countries in the sample (S_{CR}^{rest}) is

$$S_{CR}^{rest}(i \rightarrow j) = 100. \left(\frac{\sum_{j=1}^{43-N} I_{CR,j}}{N} \right) \; j = \text{remaining } 43 - N \text{ countries}, \tag{18}$$

where $43 - N$ is the number of the countries not in the high-debt group.

4 Empirical Results

Our empirical analysis begins by examining the evolution and duration of crisis severity over the three episodes of crisis. The results of rolling indices of crisis severity are presented to analyze whether the transmission of crises across countries can be related to similar debt conditions, trade, and regional linkages.

Table 4:
The largest trading partners of crisis countries in the year prior to their crisis. Value of trade (export plus imports) (US$bn) and percentage of total trade. The largest trading partners are selected based on the distribution of the ratio of total trade using a threshold of the 80^{th} percentile. The data is collected from IMF's Direction of Trade Statistics.

Crisis country	Partners	Trade	% of total trade
US (2006)	Canada	538.08	18.21
	China	361.01	12.22
	Mexico	334.68	11.33
	Japan	211.89	7.17
	Germany	132.54	4.49
	UK	100.02	3.39
	Korea	80.09	2.71
US (2007)	Canada	566.04	17.81
	China	405.36	12.76
	Mexico	349.43	11.00
	Japan	212.09	6.67
	Germany	146.29	4.60
	UK	108.39	3.41
	Korea	84.02	2.64
	France	70.32	2.21
Greece(2009)	Germany	11.49	12.02
	Italy	10.85	11.34
	France	4.74	4.96
	Russia	4.60	4.81
	Netherlands	4.49	4.70
	China	4.46	4.67
	Korea	3.49	3.65
	UK	3.47	3.62

4.1 Crisis Severity Windows

Crisis severity windows are shown in Figure 1 to analyze the percentage of countries that are affected by contagion over the three financial crises. If the index of crisis severity takes a value of 0, then over the previous 30 days there is no evidence of contagion through a particular channel. If the index takes a value of 100, then all recipient countries are affected by contagion during the crisis.

Figure 1 plots the six windows of crisis severity indices in equity markets through the correlation channel (CR), the co-skewness channels (CS_1 and CS_2), the co-volatility channel (CV), and the co-kurtosis channels (CK_1 and CK_2). The index of crisis severity is calculated by using equation (13) for the correlation channel. The same approach is applied for the calculation of the crisis severity indices for the co-skewness, co-volatility, and co-kurtosis channels, respectively. Each crisis severity window spans from September 2007 to December 2013, covering the three crises of the subprime mortgage crisis, the Great Recession and the European debt crisis. The results indicate that the correlation channel shows the most significant evidence of contagion for all 43 markets, followed by the co-kurtosis and co-volatility channels, with the co-skewness channels the least important over the three crises. Nearly an average of 50% of countries are affected by contagion through the correlation channel, but the co-skewness channels are in operation only with an average of 20% of countries affected by crises.

The European sovereign debt crisis seems to be the most pervasive crisis among the three crises, as indicated by several clusters of high peaks of the indices of crisis severity for all channels. In particular, the CR and CK_2 channels are likely to affect a large number of countries (80%) at different sub-periods of the European sovereign debt crisis, while the CS_1 channel often consistently affects a small number of countries (20%) during the period. For other channels of CV and CK_1, they affect a large number of countries at any one time in the early period of the European debt crisis.

It is interesting that the subprime mortgage crisis affects a small number of countries (10%) on average through the higher order channels, while for the correlation channel, nearly 20% of countries are affected. It is not surprising that 40% of countries are affected by contagion for a couple of days before one month of March 2008 since one of the major US financial institutions, Bear Stearns, was rescued by the Fed using emergency funding.

As expected, the indices for the correlation, co-volatility, and co-kurtosis channels reveal a rather sharp peak after September of 2008 (the collapse of Lehman brothers)

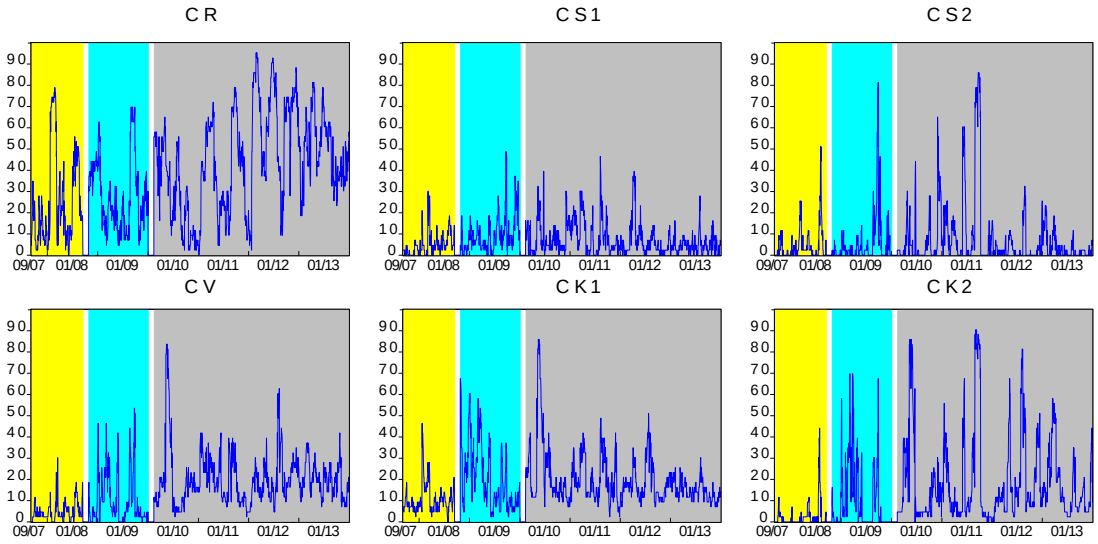

Figure 1: Percentage of markets affected by contagion through the correlation (CR), co-skewness (CS_1 and CS_2), co-volatility (CV), and co-kurtosis channels (CK_1 and CK_2) over the three financial crises. The shade areas refer to three episodes of crisis: (i) the subprime mortgage crisis (Sep 6, 2007 to Sep 12, 2008); (ii) the Great Recession (Oct 27, 2008 to Dec 31, 2009); and (iii) the European soveriegn debt crisis (Feb 12, 2010 to Dec 31, 2013).

over the Great Recession period. Around 50% of countries are affected by contagion through these three channels. The percentage is smaller for the co-skewness channels, but it jumps to 80% (CS_2) for a couple of days before the European sovereign debt crisis.

4.2 Crisis Severity and Fiscal Conditions

In order to explain whether the transmission of crises across countries can be related to fiscal conditions, the rolling indices of crisis severity are computed and displayed in Figures 2 and 3 over the three episodes of crisis from September 2007 to December 2013. In each panel of the figure, the solid (black) line presents the indices calculated for all of the 43 recipient countries, and the indices are set out in equation (13) for the correlation channel (S_{CR}), equation (14) for the first type of overall channels (S_{Total_1}), and equation (15) for the second type of overall channels (S_{Total_2}). The figures also present the same indices calculated for the countries in the high-debt group in equation (17) as a dotted (red) line, and indices calculated for the remaining countries ($43-N$)

in equation (18) as a dashed (blue) line.[6]

Figure 2 shows the crisis severity windows over three episodes of crisis based on different types of fiscal conditions, proxied by the public debt, private debt, and external debt as a percentage of GDP. For the public debt panel, there is little difference between crisis rates of the high-debt countries and the remaining countries for the subprime mortgage crisis and the Great Recession through the correlation and two types of overall channels (S_{CR}, S_{Total_1}, and S_{Total_2}). The results are rather different for the European sovereign debt crisis, where the high-debt countries are more affected by contagion than the rest of the countries through three types of channels. In particular, the correlation channel is most dominant than other channels, with 100% of countries in the high-debt group affected for several clusters of short periods during the crisis. This result provides some evidence that public debt to GDP ratio can be treated as a major warning indicator of sovereign debt crises. The result is consistent with the results suggested by Reinhart and Rogoff (2011) that public debts rise markedly as a sovereign debt crisis draws near.

Turning to the private and external debt panels, the results reveal that the high-debt countries, in terms of either domestic private credit or external debt, are much more exposed to contagion risk during the three crises of 2007 to 2013, not only through the correlation channel (S_{CR}) but also through the higher order co-moment channels (S_{Total_1} and S_{Total_2}). Again, compared with higher order channels, the correlation channel is the most dominant, with up to 80% of countries affected continually for several clusters of weeks or months during the three crises. It is not surprising that the crisis rate for the high-debt group remains significantly higher than the rest of the countries at specific periods such as the first quarter of 2008 (banking system bailouts), the last quarter of 2008 (collapse of Lehman brothers), the second quarter of 2010 (Greek bailout), and the first quarter of 2011 to the last quarter of 2013 (European sovereign defaults). This result provides some evidence that the indicators for domestic private credit and external debt as a percentage of GDP play a dominant role in explaining the spread of crises of 2007 to 2013. Our results are consistent with the results in Reinhart and Rogoff (2011) that external debt surges are an antecedent to banking crises (the Collapse of Lehman brothers in 2008). Reinhart and Rogoff (2011) find that domestic banking crises continue to be a significant predictor of debt crises.

[6] N is selected based on Tables 2 and 3 in Section 3.2.

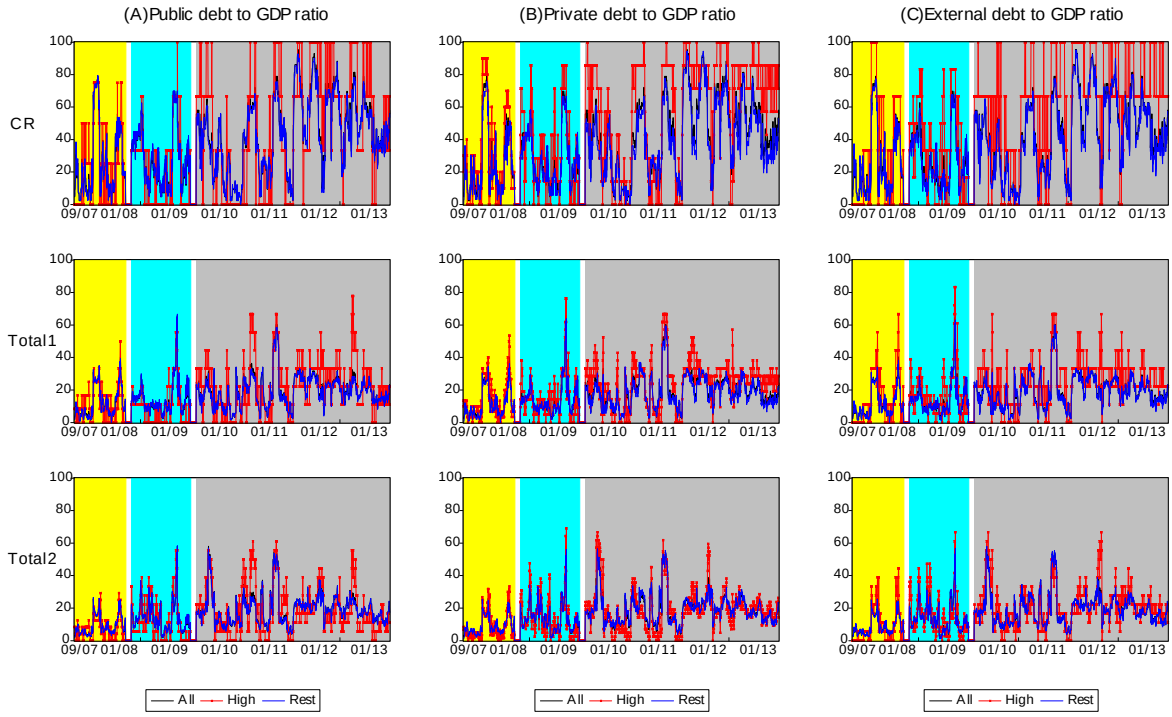

Figure 2: Percentage of countries affected by contagion related to debt conditions over the three financial crises through a particular channel. CR denotes the correlation channel, Total1 denotes the overall channels of correlation and co-skewness, and Total2 denotes the overall channels of correlation, co-skewness, co-volatility and co-kurtosis The shade areas refer to three episodes of crisis: i) the subprime mortgage crisis (Sep 6, 2007 to Sep 12, 2008); ii) the Great Recession (Oct 27, 2008 to Dec 31, 2009); and iii) the European debt crisis (Feb 12, 2010 to Dec 31, 2013). All countries (All), the countries in the high-debt group (High), and the rest of the countries in the sample (Rest).

To explore if the financial crisis is triggered by deteriorating fiscal and current account deficits, the indices of crisis severity over three episodes of crisis are presented in Figure 3, where the country's fiscal weaknesses can be measured by the fiscal account balance, current account balance, and both account balances as a percentage of GDP. A large deficit may have signalled a deteriorative fiscal position for a country. In each panel of the figure, the solid (black) line presents the incidence of crisis for all of recipient countries ($J = 43$). For the dotted (red) line, it presents the incidence of crisis for the high-deficit group of countries (N). For the dashed (blue) line, it is the incidence of crisis for the rest of the countries in the sample ($43 - N$).

As the fiscal deficit panel shows, the countries that run the largest negative fiscal balances are found to have much higher crisis rates on average than the remaining countries during the European debt crisis, while the subprime mortgage crisis and the Great Recession do not have any significant difference of crisis rates between the high-deficit group and the remaining group for the three types of channels. The important role of fiscal balance in explaining the transmission of the European debt crisis is found not only through the correlation channel (S_{CR}) but also through the higher order co-moment channels (S_{Total_1} and S_{Total_2}), as the gap of crisis rates between the countries in the high-deficit group and the remaining countries is significant large. This result indicates the importance of not just focusing on the correlation channel, but higher order co-moment channels are also important in explaining the transmission of crisis, especially for the European debt crisis.

The second column of Figure 3 shows that the incidence of crisis for the countries with the largest current account deficits are sometimes higher than the remaining countries during the three episodes of crisis. Compared with the role of fiscal account balances for detecting contagion, current account balances play a less important role in explaining the propagation of financial shocks during the subprime and the European debt crises. This result is different from the Great Recession crisis, where the crisis rate for the countries in the high-deficit group is much higher than the remaining group in the last quarter of 2008 and 2009, with nearly 100% of countries affected by this crisis through the correlation channel and 80% of countries affected through higher order co-moment channels.

Turning to the fiscal and current account balances panel, the results show that twin deficits as a percentage of GDP provide a significant role in explaining the transmission of crisis, particularly in European sovereign debt crisis. As anticipated, the crisis rate

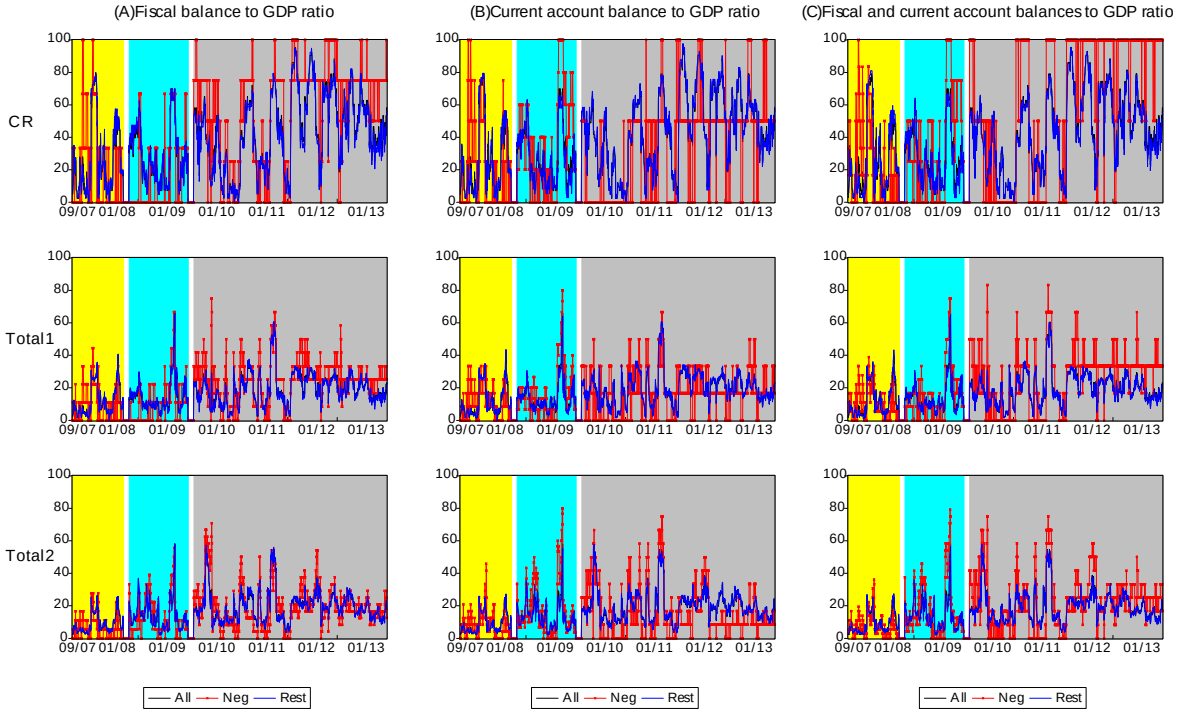

Figure 3: Percentages of countries affected by contagion related to fiscal and current account conditions through a particular channel. CR denotes the correlation channel, Total1 denotes the overall channels of correlation and co-skewness, and Total2 denotes the overall channels of correlation, co-skewness, co-volatility and co-kurtosis. The shade areas refer to three episodes of crisis: i) the subprime mortgage crisis (Sep 6, 2007 to Sep 12, 2008); ii) the Great Recession (Oct 27, 2008 to Dec 31, 2009); and iii) the European debt crisis (Feb 12, 2010 to Dec 31, 2013). All countries (All), the countries in the high-deficit group (negative fiscal or current account level relative to GDP) and rest of the countries (Rest).

for the countries with twin deficits is higher, on average, than that for the countries with either fiscal deficit or current account deficit over the last two years of the European debt crisis. The results are rather different for the subprime and the Great Recession crises, where crisis rates for the high-deficit group are lower than the remaining group for several cluster of short periods through the correlation and higher order co-moment channels.

4.3 Crisis Severity Through the Trade and Regional Linkages

Crisis severity measured through the trade and regional linkages during the three episodes of crisis are shown in Figure 4. In each panel of the figure, the solid (black)

line presents evidence of contagion for all 43 countries through the indicated channel. For the trade panel, the dotted (red) line presents the indices calculated for the top trading partners of each of the crisis source countries. For the regional panels, the dotted (red) line is the indices calculated for the countries in the same region as the country that the crisis originates. Overall, trade links do not necessarily accelerate changes in crisis transmission mechanisms through the correlation and higher order co-moment channels during the three episodes of crisis, but the regional linkage plays a significant role in explaining the transmission of the European debt crisis, not for the subprime crisis and the Great Recession.

As the trade panel shows, for the subprime crisis, the incidence of crisis for the major trading partners is quite identical to that for the rest of the countries through the three types of channels. For the Great Recession and the European debt crisis, there is no distinction of the crisis rates between the top trading partners and the rest of the countries through the high order channels, but a little difference of crisis rates are found through the correlation channel in the last quarter of 2008.

Turning to the regional panels, the results show that the regional linkage plays a significant role in explaining the transmission of crisis, especially for the European debt crisis, but not for the subprime crisis and the Great Recession. The crisis, which is mainly regional, is the European debt crisis, where the crisis is spread over the European region, not only through the second and third order channels, but also through the fourth order co-moments. Nearly 90% of European countries are affected by contagion from Greece for the correlation channel, but for the overall channels of contagion, it is less than 60% of European countries affected. The regional linkages do not provide a dominant role in explaining the transmission of the subprime crisis and the Great Recession. More specifically, the crisis rates for the Latin American region are identical to those for the remaining regions through the overall channels during the subprime crisis and the Great Recession.

5 Conclusions

Three episodes of financial crisis from 2007 to 2013, beginning with the US subprime mortgage delinquencies in mid-2007, led to a sharp decline in stock market indices in the US. The shocks quickly spread to a wide range of markets and countries around the world, with a clear channel of the shock transmission through linkages arising

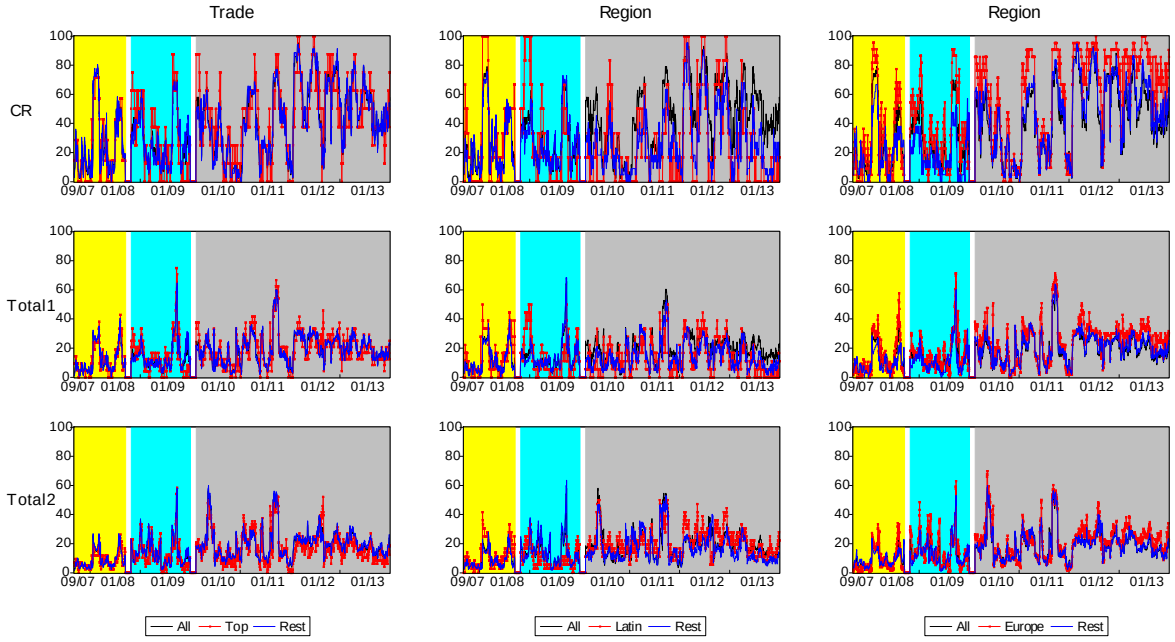

Figure 4: Percentages of countries affected by contagion related to trade and regional linkages over the three financial crises. CR denotes the correlation channel, Total1 denotes the overall channels of correlation and co-skewness, and Total2 denotes the overall channels of correlation, co-skewness, co-volatility and co-kurtosis. The shade areas refer to three episodes of crisis: i) the subprime mortgage crisis (Sep 6, 2007 to Sep 12, 2008); ii) the Great Recession (Oct 27, 2008 to Dec 31, 2009); and iii) the European debt crisis (Feb 12, 2010 to Dec 31, 2013). All countries (All), the top trading partners (Top), countries in the same region as the country that crisis originates, and rest of the countries (Rest).

from fiscal conditions, trade, and regional proximity, and fiscal and macroeconomic variables. In this paper, we have investigated the role of fiscal weaknesses, external and internal imbalances, trade and regional linkages in explaining the transmission of the three episodes of crisis from 2007 to 2013.

Several indices of crisis severity were constructed based on the six tests of contagion developed by Fry et al. (2010) and Fry-McKibbin and Hsiao (2014) to measure the percentage of countries that are affected by contagion through a particular channel. We use the daily equity indices (high-frequency data) for 44 countries to investigate the role of fiscal and macro fundamentals instead of using the low-frequency data considered in most of the literature. In this case, the crisis severity indices are allowed to vary over the period of crisis so that the peak level of crisis can be identified at a specific date.

The results indicate that the European sovereign debt crisis is the most pervasive among the three crises of 2007-13, as the crisis severity remains extremely high over the episode, not only through the correlation channel, but also through higher order co-moment channels. Notably, the second and fourth order co-moments channels affect a large number of countries, while the third order co-moments channels affect a small number of countries during the European debt crisis. As for the subprime crisis and the Great Recession, a large number of countries are affected by contagion from the US at specific times such as the first quarter of 2008 (banking system bailouts) and the last quarter of 2008 (collapse of Lehman brothers).

As the recent European sovereign debt crisis is characterized by a serious deterioration of fiscal and macroeconomic conditions for most countries in Europe, this paper analyzes the indicators for public, private, and external debts, domestic, and external imbalances, as well as trade, and regional linkages in explaining the propagation mechanism of financial shocks across equity markets during the three episodes of crisis of 2007-13. A variety of fiscal and macroeconomic variables in each year prior to a crisis are analyzed to examine whether the incidence of crisis severity differs significantly between countries with weak fiscal and macroeconomic conditions and the rest of the countries in the sample. The variable can be treated as an early warning indicator of the crisis if the difference in crisis severity between countries with weak market fundamentals and remaining countries is significantly large.

The results indicate that along with regional linkages, a country's fiscal conditions play a significant role in explaining the transmission of crises, especially for the European debt crisis, while the trade linkages do not necessarily accelerate changes in

crisis transmission. In particular, significant evidence of contagion is found during the three crises from 2007-13 if the country has larger private debt, external debt, or both fiscal and current account deficits than the rest of the countries in the year prior to the crisis. This result indicates that private and external debts as well as the fiscal and current account balances can be treated as early warning indicators of the three episodes of crisis from 2007-13. However, public debt and the fiscal account balance can be treated as early warning indicators only for the European debt crisis, not for the subprime mortgage and the Great Recession. Our findings are consistent with the results in Reinhart and Rogoff (2011) that public debts rise markedly as a sovereign debt crisis draws near.

Trade linkages do not accelerate changes in transmission of crisis as the difference in crisis severity between the top trading partners and the rest of the countries in the sample is similar during the three crises of 2007-13 for each particular channel. A strong regional linkage is found during the European sovereign debt crisis, not only through the correlation channel, but also through higher order co-moment channels.

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