Contagion across US and EU financial markets: Evidence from the CDS markets

Nicholas Apergis [♦,] Christina Christou[♣], Jason Kynigakis [♠]

Abstract

This study investigates whether contagion occurred during the recent global financial crisis across EU and US financial markets. The methodology used to test for contagion is the Forbes and Rigobon cross-correlation test, the Li and Zhu non-parametric test, the Fry et al. coskewness test and the Hsiao cokurtosis and covolatility tests. These tests are applied to a set of bank sector CDS, insurance sector CDS, sovereign bonds, equity and volatility indices. The findings indicate significant evidence of contagion, especially through the channels of higher order moments.

Keywords: Cokurtosis; Correlation; Coskewness; Covolatility; Financial contagion; Financial crisis

JEL Classification: G15, G01, C58, F36

[♦] University of Piraeus, Department of Banking and Financial Management, Greece. Email: napergis@unipi.gr and University of Derby, School of Business, Law and Social Sciences, UK, n.apergis@derby.ac.uk

[♣]Corresponding author. Open University of Cyprus, School of Economics and Finance, Cyprus. Email: christina.christou@ouc.ac.cy.

[♠] University of Kent, Kent Business School, UK. Email: *ik210@kent.ac.uk.*.

1. Introduction

The 2007-2008 financial crisis, originated in the US subprime mortgage market and spread with devastating effects to the rest of the sectors of the US economy, as well as the global financial markets, is considered to be the most serious recession since World War II. The problem in the mortgage market, which was a relatively small part of the US economy, spread to other financial sectors through the Collateralized Mortgage Obligations (CMOs), which are a type of collateralized debt obligations (CDOs). The problems in the mortgage market became more pronounced by the presence of credit default swaps (CDS), which were used as an insurance contract for the various CMOs. The plunge of the prices in the mortgage markets caused the CMOs to drop in value and since the demand of CMOs was very low they were no longer being traded, making it difficult to price them. This triggered the protection payments of the CDSs and caused financial institutions to suffer great losses. The default of Lehman caused substantial turmoil to the global financial markets, leading to the failure of a number of financial institutions and investors selling high risk assets, such as stocks and derivative securities, causing a sharp drop in asset prices.

There are numerous studies that examine how a crisis transmits through the CDS channel, as well as the degree of comovements between CDSs and other asset classes. Some recent research on the relationship between sovereign bonds and CDS includes those of Pan and Singleton (2008), Longstaff et al. (2011), and Ang and Longstaff (2013). A strand of literature that focuses on bank sector CDS includes those by Acharya et al. (2014) who focus on financial sector bailouts and document, using CDS data, that both bank and sovereign credit risks are linked. Similar results are provided by Kallestrup et al. (2016)

41 who highlight that sovereign CDS premiums are significantly affected by the foreign asset

42 holdings of their domestic banks. Other studies include, those by Eichengreen et al. (2012)

43 who focus on individual bank level CDS data to examine the international transmission

44 channels of the US subprime crisis. In a related study, Dooley and Hutchison (2009)

45 explore the effect of various news announcements on CDS spreads during the crisis.

46 Furthermore, Jorion and Zhang (2007, 2009) use stock and CDS data to investigate the

47 effects and various channels of credit contagion. Finally, Billio et al. (2014) examine the

48 changes in sovereign and credit risk by analyzing the link between sovereign, bank and

49 insurance sectors.

50 The global financial crisis shows that a shock in a small part of the US economy was

51 transmitted to the rest of the sectors of the economy and then spread globally. Such market

52 comovements can have adverse effects to investors wishing to differentiate their portfolios,

53 as well as on the decisions of domestic and international policy makers. The first goal of

54 this study is to investigate whether contagion occurred across the European and the US

55 financial markets after the shock of the September 15th, 2008, which is the date when

56 Lehman Brothers filed for Chapter 11 bankruptcy, specifically between equity, sovereign

57 bond, bank sector CDS and insurance sector CDS markets. Secondly, the analysis

58 investigates contagion patterns, which arise not only through linear dependence (i.e.

59 correlation), but also through asymmetric and extremal cross market dependence.

60 Specifically, in order to draw a more complete picture of contagion, the paper explores four

61 different channels of contagion using statistical tests based on correlation, coskewness,

62 cokurtosis and covolatility. Before shedding light to these issues, we briefly refer to the

63 definition of contagion used in our analysis.

64   In this study we adopt the same definition for contagion as in Forbes and Rigobon

65   (2002), namely "shift-contagion". The authors distinguish between "normal"

66   interdependence, which is a high level of interconnectedness across markets during all

67   states of the world, and contagion which is a significant increase in cross-market linkages

68   after a shock has occurred to one or more markets. The normal level of interdependence

69   might be due to preexisting market linkages, such as trade channels, financial flows, and

70   exposure to common shocks. The presence of "shift-contagion" implies that a shock,

71   defined as a high volatility event, has caused the normal interconnectedness between

72   markets to become unstable. The main advantage of this definition is that it provides a clear

73   empirical framework, which allows us to test whether the linkages between two markets

74   increased in the crisis period compared to the tranquil period prior to the crisis.

75   Furthermore, it provides a broad view of contagion, which enables us to explore different

76   channels of contagion, both linear and nonlinear. [1]

77   A decrease in asset returns and an increase in volatility is a common characteristic of a

78   financial crisis. This is consistent with a risk-averse investor realizing higher returns in the

79   pre-crisis period, in exchange for undertaking greater risk in the crisis period (see Sharpe,

80   1964; Lintner, 1965; Black, 1972). The earliest tests for contagion (King and Wadhwani

81   (1990)), focused on whether the cross-correlation between the asset returns of two markets

82   changed during the crisis period compared to the pre-crisis period. The base approach we

83   use to examine for evidence of contagion across financial markets follows the correlation

---

[1] An extensive review of the literature of financial contagion, including the various definitions and different empirical approaches used to measure contagion is provided by Dornbusch et al. (2000), Pericoli and Sbracia (2003), Dungey et al. (2005) and Forbes (2012).

84   analysis framework developed by Forbes and Rigobon (2002), who correct for the bias due

85   to the presence of heteroskedasticity in market returns that is inherent in earlier correlation

86   tests.

87   However, there is considerable evidence that the distribution of asset returns cannot be

88   adequately described by the first two moments (see among others Kraus and Litzenberger,

89   1976 and Harvey and Siddique, 2000). Several authors (Harvey and Siddique, 2000; Smith,

90   2007; Poti and Wang, 2010) show that coskewness and cokurtosis can be highly important

91   dimensions of risk. Kostakis et al. (2012) document that stock returns with negative

92   coskewness and positive cokurtosis values, i.e., with respect to the market portfolio returns,

93   yield significant premiums over counterpart firms with positive coskewness and negative

94   cokurtosis, respectively. An important characteristic of asset returns is that the return

95   distribution after a shock switches from negative skewness to positive skewness, which can

96   be attributed to investors preferring assets whose returns are right-skewed to asset returns

97   that are left-skewed (Fry et al., 2010). An additional feature of asset returns is that they

98   exhibit leptokurtic behavior, with kurtosis rising during the crisis period. Brunnermeier and

99   Pedersen (2009) show that the lower kurtosis observed during the tranquil period is due to

100   investors preferring securities with positive return and negative skewness. However, they

101   find that after a crisis, investors end up holding securities with negative returns and

102   negative skewness, leading to higher kurtosis. Fry et al. (2018) establish a theoretical

103   motivation for testing for higher order moments by connecting the higher order comoments

104   with the risk properties of agents' utility functions. Hasler and Ornthanalai (2018) suggest

105   that financial contagion arises because investors pay fluctuating attention to news.

106 Specifically, they show theoretically and empirically that as a negative shock hits one

107 market, investors pay more attention to it.

108   The first of the methodologies we use to search for transmission channels operating

109 through higher order comoments, was developed by Fry et al. (2010), who propose a new

110 class of tests for financial contagion based on changes in asymmetric dependence, which

111 is measured by coskewness (the relationship between the returns and volatility). They show

112 that the coskewness based tests identify additional transmission channels, which are not

113 detected by tests based on correlation. More recently, Fry-McKibbin and Hsiao (2018),

114 develop a new line of tests based on extremal dependence. Their tests capture changes in

115 various aspects of the distributions of asset returns, such as cokurtosis (the relationship

116 between the returns and skewness) and covolatility (the relationship between the volatility

117 of two markets).

118   Our initial findings based on correlation tests indicate that contagion occurred both

119 within and across European and US financial markets, with the US insurance sector CDS

120 and European equities being the most affected. The coskewness test exposed new channels

121 of contagion, particularly among bank and insurance CDS and also between them and the

122 majority of the remaining indices. The results based on extremal dependence (i.e.,

123 cokurtosis and covolatility) revealed additional cross-market linkages which further

124 underline the systemic importance of the bank and insurance sector. The cokurtosis tests

125 showed that contagion was widespread within the US market, but also transmitted across

126 US and European indices. Finally, the covolatility test found significant contagion effects,

127 especially through the channels of the CDS, equity and bond markets.

128   The remaining of the paper proceeds as follows; Section 2 describes the tests for

129   contagion used in this study. Section 3 describes the data and presents the empirical

130   analysis. Finally, Section 4 concludes the paper.

131   **2. Methodological approaches**

132   This section provides a brief description of statistical tests used to examine linear and

133   nonlinear channels of financial contagion. The linear (mean) channel of contagion is

134   investigated using the correlation-based contagion tests proposed by Forbes and Ribogon

135   (2002). Furthermore, the asymmetric dependence test developed by Fry et al (2010) are

136   employed to study the coskewness channel of contagion. Lastly, the Fry-McKibbin and

137   Hsiao (2018) extremal dependence tests are used to explore the cokurtosis and covolatility

138   channels.

139   Prior to testing for contagion, the sample is divided into two sets, the tranquil period

140   prior to the crisis and the period after the occurrence of the shock (i.e. the crisis period).

141   The pre- and crisis periods are denoted as x and y. The sample sizes are T for the full

142   sample, T_x for the pre-crisis period and T_y for the crisis period. The correlation between

143   the asset returns for the two markets is ρ_x for the non-crisis period and ρ_y for the crisis

144   period. Let the source asset market be denoted as i and the recipient market of contagion

145   as j. The asset returns are r_i and r_j for markets i and j respectively. The means of asset

146   returns for i and j during the pre- and crisis periods are $\mu_{x,i}$, $\mu_{x,j}$, $\mu_{y,i}$ and $\mu_{y,j}$, while the

147   standard deviations of asset returns for i and j during the pre- and crisis periods are $\sigma_{x,i}$,

148    $\sigma_{x,j}$, $\sigma_{y,i}$ and $\sigma_{y,j}$.

149   *2.1 Contagion test based on changes in correlation*

150   Forbes and Rigobon (2002) define contagion as an increase in the heteroskedasticity

151   adjusted correlation coefficient, which is defined as:

$$v_y = \frac{\rho_y}{\sqrt{1 + \delta(1 - \rho_y^2)}}, \quad \text{where } \delta = \frac{\sigma_{y,i}^2 - \sigma_{x,i}^2}{\sigma_{x,i}^2} \tag{1}$$

152

153   The authors estimate a vector autoregressive model (VAR) model and use the variance-

154   covariance estimates from this model to calculate the unconditional correlation coefficient

155   between the market where the shock originated and a recipient market. Furthermore, they

156   make the assumptions that there are no omitted variables and endogeneityand use t-tests

157   to examine if there is a significant increase in any of the correlation coefficients during the

158   crisis period. The "no contagion" null, $H_0: v_y = \rho_x$, against the "contagion" alternative,

159    $H_1: v_y > \rho_x$, is tested using the following statistic:

$$FR(i \rightarrow j) = \frac{\frac{1}{2} ln\left(\frac{1 + \hat{v}_y}{1 - \hat{v}_y}\right) - \frac{1}{2} ln\left(\frac{1 + \hat{\rho}_x}{1 - \hat{\rho}_x}\right)}{\sqrt{\frac{1}{T_y - 3} + \frac{1}{T_x - 3}}}. \tag{3}$$

160

161   The Forbes and Ribogon (2002), $FR(i \rightarrow j)$, statistic examines the linear (correlation)

162   channel of contagion. Specifically, it tests for contagion from the expected returns of

163   market i to the expected returns of market j.

164   *2.2 Contagion tests based on changes in coskewness*

165   Fry et al. (2010) argue that linear (correlations) channel is not enough to fully reveal

166   all patterns of contagion, and that important information can be obtained from asymmetric

167   dependence. The coskewness channel of contagion captures changes in coskewness which

8

168 emerge from the interaction between expected returns and volatility across markets. To

169 explore the coskewness channel of contagion Fry et al. (2010) developed the following

170 statistic:

171
$$CS_{mn}\left(i \to j; r_i^m, r_j^n\right) = \left(\frac{\hat{\psi}_y\left(r_i^m, r_j^n\right) - \hat{\psi}_x\left(r_i^m, r_j^n\right)}{\sqrt{\frac{4\hat{v}_y + 2}{T_y} + \frac{4\hat{\rho}_x^2 + 2}{T_x}}}\right)^2,$$
(4)

172 where $\quad \hat{\psi}_k\left(r_i^m, r_j^n\right) = \frac{1}{T_k}\sum_{t=1}^{T_k}\left(\frac{r_{i,t}-\hat{\mu}_{k,i}}{\hat{\sigma}_{k,i}}\right)^m\left(\frac{r_{j,t}-\hat{\mu}_{k,j}}{\hat{\sigma}_{k,j}}\right)^n, \quad k = x, y,$
(5)

173 $m, n = 1, 2$ and $\hat{v}_y$ the estimator of v_y defined in (1).

174   The CS_{12} (CS_{21}) coskewness contagion test examines whether a change to the expected

175 returns (volatility) of the source market led to a change to the volatility (expected returns)

176 of the recipient market. To test whether there is a significant change in coskewness, they

177 formulate the following hypotheses:

178
$$H_0: \psi_y\left(r_i^m, r_j^n\right) = \psi_x\left(r_i^m, r_j^n\right), \quad H_1: \psi_y\left(r_i^m, r_j^n\right) \neq \psi_x\left(r_i^m, r_j^n\right),$$
(7)

179 where $m, n = 1, 2$. Under the null hypothesis of "no contagion", coskewness contagion

180 tests are asymptotically distributed as: $CS_{12}(i \to j), CS_{21}(i \to j) \xrightarrow{d} X_1^2$.

181 *2.3 Contagion tests based on changes in cokurtosis*

182   The coskewness test is not always enough to capture the full scope of contagion.

183 Additional transmission channels may arise through extremal dependence. The cokurtosis

184 channel of contagion captures the interaction between expected returns and skewness

9

185 across markets. To detect contagion from the source market i to the recipient market j

186 through the cokurtosis channel Fry-McKibbin and Hsiao (2018) suggest the following

187 statistic:

188
$$CK_{mn}\left(i \rightarrow j; r_i^m, r_j^n\right) = \left(\frac{\hat{\xi}_y\left(r_i^m, r_j^n\right) - \hat{\xi}_x\left(r_i^m, r_j^n\right)}{\sqrt{\frac{18\hat{v}_y^2 + 6}{T_y} + \frac{18\hat{\rho}_y^2 + 6}{T_x}}}\right)^2, \quad \text{where} \tag{8}$$

189
$$\hat{\xi}_y\left(r_i^m, r_j^n\right) = \hat{\psi}_y\left(r_i^m, r_j^n\right) - \left(3\hat{v}_y\right), \quad \hat{\xi}_x\left(r_i^m, r_j^n\right) = \hat{\psi}_x\left(r_i^m, r_j^n\right) - \left(3\hat{\rho}_x\right), \tag{9}$$

190 $m, n = 1, 3$ and $\hat{v}_y$ the estimator of v_y defined in (1).

191 The first (second) statistic, CK_{13} (CK_{31}), detects contagion from the expected returns

192 (skewness) of the source market i to the skewness (expected returns) of the recipient market

193 j. To test whether there is a significant change in cokurtosis, the following hypotheses are

194 made:

195
$$H_0: \xi_y\left(r_i^m, r_j^n\right) = \xi_x\left(r_i^m, r_j^n\right), \quad H_1: \xi_y\left(r_i^m, r_j^n\right) \neq \xi_x\left(r_i^m, r_j^n\right). \tag{10}$$

196 Under the null hypothesis of "no contagion", tests of contagion based on changes in

197 cokurtosis are asymptotically distributed as: $CK_{13}(i \rightarrow j), CK_{31}(i \rightarrow j) \xrightarrow{d} X_1^2$.

198 *2.4 Contagion test based on changes in covolatility*

199 Changes in the relation between the returns volatility of one market with the returns

200 volatility of another market from negative to positive after the shock has occurred, reveals

201 the volatility smile effect through the covolatility channel in the crisis period. The

202 covolatility statistic, proposed by Fry-McKibbin and Hsiao (2018), for testing for

203 contagion from market i to market j is given by the following equation:

$$CV_{22}\left(i \to j; r_i^2, r_j^2\right) = \left(\frac{\hat{\xi}_y\left(r_i^2, r_j^2\right) - \hat{\xi}_x\left(r_i^2, r_j^2\right)}{\sqrt{\dfrac{4\hat{v}_y^4 + 16\hat{v}_y^2 + 4}{T_y} + \dfrac{4\hat{\rho}_x^4 + 16\hat{\rho}_x^2 + 4}{T_x}}}\right)^2, \quad \text{where} \quad (11)$$

205
$$\hat{\xi}_y\left(r_i^2, r_j^2\right) = \hat{\psi}_y\left(r_i^2, r_j^2\right) - \left(1 + 2\hat{v}_y^2\right), \quad \hat{\xi}_x\left(r_i^2, r_j^2\right) = \hat{\psi}_x\left(r_i^2, r_j^2\right) - (3\hat{\rho}_x). \quad (12)$$

206 To test whether there is a significant change in covolatility, the following hypotheses

207 are made:

208
$$H_0: \xi_y\left(r_i^2, r_j^2\right) = \xi_x\left(r_i^2, r_j^2\right), \quad H_1: \xi_y\left(r_i^2, r_j^2\right) \neq \xi_x\left(r_i^2, r_j^2\right). \quad (13)$$

209 Under the null hypothesis of "no contagion", tests of contagion based on changes in

210 covolatility are asymptotically distributed as: $CV_{22}(i \to j) \xrightarrow{d} X_1^2$.

211 **3. Data and empirical analysis**

212 The dataset is composed of daily observations of the equity, volatility, government

213 bond, insurance sector CDS and bank sector CDS indices for Europe and the US. The

214 analysis focuses on assets in relevance to the banking sector, thus exemplified the role of

215 this sector in stressful times. In particular, many studies exemplify the fact that crisis events

216 usually trigger systemic events through the banking sector, while several authors have

217 identified strong evidence that bank values co-vary both in tranquil, but mainly in stressful

218 periods, either as a result of common shocks, or as a consequence of trouble at one bank

219 (Iyer and Peydro, 2011). Moreover, explanations of systemic risk fall into three broad and

11

overlapping categories. The first defines systemic risk as exposure to a common shock. If all banks have an exposure to commercial real estate loans, then a shock to the real estate sector causes losses to every bank in the system with serious detrimental effects to the real economy. This type of exposure could arise as a natural consequence of bank diversification (Wagner, 2010), or it could also reflect a strategic decision to take advantage of limited liability so as to externalise some of the costs of failure (Acharya, 2009), or to capitalise upon the regulator's unwillingness to allow many banks to fail together (Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012). The second approach to systemic risk is concerned with structural funding risks in the banking sector. Precisely, because banks fund long-lived and hard-to-sell assets with short-dated deposits and wholesale loans, they are exposed to runs, either by depositors or short-term bank lenders. It is well-understood that an unexpectedly large withdrawal of funds can cause bank insolvency (Diamond and Dybvig, 1983). When such phenomena happen, a problem that could have been contained within a few banks is transmitted to the entire banking sector, and causes widespread bank failure (Allen and Gale, 2000; Freixas, Parigi, and Rochet, 2000). Finally, a final strand of the literature on contagion concentrates upon the topology of the networks through which shocks are transmitted. Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) show that densely-connected networks are better able to absorb small shocks, but that they amplify the effects of larger shocks, such as crisis events. May, Levin, and Sugihara (2008) and Haldane and May (2011) explain the propagation of shocks through banking.

All indices are retrieved from Datastream and reported in Table A1 in the Appendix. Specifically, the two equity indices are the Euro Stoxx 50 index (EUEQ) and the S&P 500 index (USEQ), for Europe and the US respectively. The VSTOXX (EUVOL) is a volatility

index based on option prices on the Euro Stoxx 50 index, while the CBOE volatility index

or VIX (USVOL) is based on options written on the S&P 500 index. The bond indices for

the European Monetary Union (EMU) and the US (EMUGB and USGB respectively) are

based on five-year sovereign bonds. Finally, the credit default swaps indices are based on

Thomson Reuter's five-year CDS data for the European and US bank (EUBCDS and

USBCDS) and insurance sectors (EUICDS and USICDS). We compute the continuously

compounded daily returns for all indices, $r_{i,t}$, using the formula: $r_{i,t} = \ln(p_{i,t}/p_{i,t-1})$,

where p_{it} denotes the daily closing price of index i on day t. The mean, standard deviation,

skewness, kurtosis and correlation coefficients of $r_{i,t}$ for the pre- and crisis periods are

reported in Table A2 of the Appendix.

The sample period is set from January 15, 2004 to January 14, 2012, for a total of 2088

observations. The crisis event is set to September 15, 2008, which is the date when Lehman

Brothers filed for Chapter 11 bankruptcy. Therefore, the sample is divided into two periods

at the date when the shock occurred; the pre-crisis period from January 15, 2004 to

September 15, 2008 and the crisis period from September 16, 2008 to January 14, 2012,

for a total of 1044 observations for each sub-period. Overall, we observe from Table A2

that all indices became more volatile, since the standard deviation increased during the

period after the shock, compared to the tranquil period.

We apply the econometric methodology described in Section 2, to investigate linear and

nonlinear channels of contagion between European and US markets during the global

financial crisis. There are three cases of contagion examined: i) contagion across European

financial markets, ii) contagion across US financial markets, and iii) contagion between

European and US financial markets.

266   To compute the Forbes and Rigobon test statistics as well as the adjusted unconditional

267   correlation coefficient needed for the coskewness, cokurtosis and covolatility tests, the

268   daily market returns are filtered with a 29-lag VAR model[2]. The residuals estimated from

269   the VAR model are used in computing the tests of contagion.

270   The results of the tests of contagion are presented in Tables 1 to 4. In each of the tables,

271   the first column indicates the source market, while the first line features the recipient

272   market. Furthermore, in each table, the upper left quarter and the lower right quarter report

273   the test results for contagion within Europe and the US, respectively. The other two

274   quarters refer to the contagion test results across Europe and the US. The figures are test

275   statistics values, while those in parenthesis are p-values. The null hypothesis is "no

276   contagion" and the rejection of the null hypothesis implies that contagion has occurred.

277   *4.1 Results of the Forbes and Rigobon (2002) correlation test*

278   Table 1 presents the empirical results of the Forbes and Rigobon (2002) test, which

279   examines contagion from the expected returns of one market to the expected returns of a

280   second market, based on a significant change in cross-correlation. The empirical findings

281   illustrate that only 26 out of the 90 entries indicate contagion at the 5% significance level.

282   **[Insert Table 1 about here]**

283   Within Europe, results suggest the presence of contagion between the equity index and

284   the bank and insurance CDS indices. Furthermore, significant contagion effects occurred

285   from the insurance sector CDS to the bank sector CDS index and from the government

---

[2] The Lagrange Multiplier autocorrelation test indicates no autocorrelations in the residuals at the 1% significance level.

bond to the equity index. Within the US, it is evident that shocks propagate between the

insurance sector CDS index and all other indices, with the exception of the equity index,

which is affected only by the bank CDS index. As for contagion across regions, we observe

that contagion runs from the US insurance CDS market to all the European indices, with

the exception of the equity index. By contrast, the US insurance CDS index is affected by

both European CDS indices and the volatility index. In addition, contagion is transmitted

to the European equity index running from the US bank CDS, sovereign bond and volatility

indices. Finally, contagion spreads from the European bank CDS index to the US equity

index and between the sovereign bond indices in both regions.

4.2 Results of the Fry et al. (2010) coskewness test

Tables 2a and 2b present the results for the coskewness tests of contagion. Results reveal

additional evidence of contagion through the coskewness channel, with 56 entries in each

table having a p-value less than the 5% significance level. The findings of the coskewness

tests indicate the systemic importance of the banking and insurance sectors (see Gropp and

Moerman, 2004 and Allen and Carletti, 2006, respectively), with contagion affects being

prominent among bank and insurance CDS and also between the CDS and the majority of

the remaining indices, for both regions.

[Insert Tables 2a and 2b about here]

The $CS12$ test results highlight the contagion linkages from the expected of one market

(source) to the volatility of a second market (recipient). It is evident that among the

European markets such contagion links originate from the sovereign bond and volatility

indices towards the equity index, while the volatility index is also affected by the equity

308   index. The sovereign bond index remains unaffected by the rest of the European indices.

309   For the US markets, apart from the bank and insurance CDS channels, contagion is found

310   to transmit from the equity index to the sovereign bond index. The $CS12$ test reveals further

311   contagion channels across the two regions, with the EMU sovereign bond and equity

312   markets affecting the US sovereign bond market, while the US volatility index is affected

313   by the European bond and volatility indices. Significant effects of contagion are revealed

314   from the US equity and sovereign bond sectors towards their European counterparts and

315   from the US volatility index to the European equity index. The European volatility index

316   is unaffected by any of the US indices.

317   The results of the $CS21$ test, which detects contagion from the volatility of one market

318   to the expected returns of a second market, are reported in Table 2b. Again, we find

319   significant evidence of contagion through the coskewness channel, originating from the

320   European and US banking and insurance sectors to the majority of the remaining indices.

321   Specifically, for the European region the $CS21$ test detects significant contagion patterns,

322   from the equity market to all other markets and from the volatility index to the bank sector

323   CDS and equity indices. The EMU sovereign bond index does not seem to affect any of

324   the other indices. In the case of the US, additional linkages include those from the sovereign

325   bond index to all indices except the volatility index, and from the equity index to the bank

326   sector CDS index. Regarding additional contagion links across the two regions, the

327   contagion effects that are most prominent, originate from both sovereign bond indices and

328   the European equity index.

329   *4.3 Results of the Fry-McKibbin and Hsiao (2018) cokurtosis test*

330   The results for the extremal dependence tests based on cokurtosis and presented in

331   Tables 3a and 3b, provide strong evidence of contagion through the fourth-order

332   comoments. The cokurtosis tests reveal an even greater number of cross-market contagion

333   linkages during the global financial crisis compared to those detected from the coskewness

334   tests. Specifically, the $CK13$ test (Table 3a) and $CK31$ test (Table 3b) detect 77 and 75

335   contagion links, respectively.

336   **[Insert Tables 3a and 3b about here]**

337   According to the $CK13$ test which captures contagion from the expected returns of the

338   source market to the skewness of the recipient market, the European bank sector CDS, the

339   insurance sector CDS and volatility indices are affected by all European indices. The equity

340   index is not affected only by the volatility index. On the other hand, contagion is

341   transmitted to the sovereign bond index only from the equity index. In the US region,

342   contagion is present across all markets during the global financial crisis. Shocks originating

343   from European markets returns spread towards all US markets skewness, with the

344   exception of the US equity index which is unaffected by both European CDS indices and

345   the US volatility index, which is unaffected by the European equity index. Contagion

346   spread towards the European bank and insurance CDS indices from all US indices, while

347   the EMU sovereign bond index is affected by its US counterpart and the US bank CDS

348   index. Moreover, contagion transmits from all US markets, except from the sovereign bond

349   index, to the European equity index. Finally, contagion spreads to the European volatility

350   index from the US insurance CDS, equity and volatility indices.

17

351   Similar results are obtained from the $CK31$ test, which detects contagion from the

352   skewness of the source market to the expected return of the recipient market. In particular,

353   in Europe, changes in cokurtosis are prominent from the bank CDS, insurance CDS, equity

354   indices and to a lesser extent from the volatility index, with the bond index affecting only

355   the equity index. Contagion is widespread across all financial markets in the US, with the

356   exception of the US insurance CDS and equity indices that do not affect the equity and

357   volatility indices respectively. Contagion effects spread from the European and US bank

358   and insurance CDS indices towards the financial markets of both regions. Furthermore,

359   contagion transmits from the European equity markets to all US markets and from the US

360   government bond and volatility indices to all European indices. The effects of contagion

361   are less prominent when the EMU sovereign bond and European volatility and the US

362   equity channels are considered as origins.

363   *4.4 Results of the Fry-McKibbin and Hsiao (2018) covolatility test*

364   The results for the covolatility test, which examines significant changes in volatility

365   spillovers after a shock, are reported in Table 4. Overall, the results suggest contagion

366   patterns similar to those obtained for the cokurtosis channel. Specifically, 76 entries in

367   Table 4 support the contagion hypothesis through the covolatility channel. This result

368   suggests that the effects of the global financial crisis were widespread across all markets

369   for both regions, especially through the banking and insurance sector CDS channels as

370   indicated by the magnitude of the $CV22$ statistic.

371   **[Insert Table 4 about here]**

18

In Europe, contagion transmits among all indices, with no evidence of contagion to the equity index from the volatility index. Furthermore, the covolatility test does not detect any contagion between the volatility of the two CDS indices and the volatility of the sovereign bond index. In the US, contagion is spread across all financial markets, with the value of the covolatility statistics related to the bank and insurance sectors being significantly higher. Based on the covolatility test, contagion across both regions is similarly extensive. The channels of contagion that are more prominent include the European insurance sector CDS, sovereign bond and volatility indices and the US bank sector CDS, sovereign bond and volatility indices.

The obtained results for the case of the US are consistent with the increasing uncertainty fueled by events, such as the collapse of the subprime mortgage market. This type of uncertainty persists, in spite of certain actions taken by the Federal Reserve and other central banks to increase liquidity available to banks. The high levels of uncertainty are also fed by the increasing instability in the European banking sector, while it also spreads to the equity market. Similar results are taken for the European markets, given that the European Central Bank did not match the actions taken by the Fed to provide higher levels of liquidity, both for the European banking sector and the real economy (Bartram and Bonard, 2009). At the same time, the presence of extended contagion clearly supports that the benefits of risk diversification diminished during crisis periods. In addition, the presence of contagion across markets is a proof of strong evidence for the 'wake-up call' hypothesis, which opens up the intriguing possibility that government policies can mitigate contagion (Goldstein et al., 2000), since domestic fundamentals are likely to play a dominant role in the transmission of the crisis. If macro-fundamentals matter during a

crisis, cross-country differences in government policies (i.e., as in the case between US and Eurozone) could potentially explain the relative exposure to the crisis. Strong contagion can also be explained in the case where European firms are in sectors that are highly integrated with US markets, such as technology. The findings are also very indicative for the validity of the 'banking channel' hypothesis for global contagion during the crisis. A number of authors have stressed the importance of this channel, even for equity market contagion (Van Rijckeghem and Weder, 2001; Tong and Wei, 2009; among others).

A central element of the crisis was a freezing of credit and inter-bank markets and a liquidity squeeze that made it difficult for financial and non-financial institutions to obtain capital. This finding is closely related to the literature that stresses the role of (il)liquidity in causing or exacerbating crise events (Adrian and Shin, 2010; Brunnermeier and Pedersen, 2009). The effect of such banking problems also clearly indicates firms with financing constraints, as well as firms with more interest rate exposures, as they may have shorter maturity debt and thus face steeper refinancing costs (Almeida et al., 2012). Finally, the results are in relevance to the concepts of risk aversion and liquidity. In particular, the risk aversion of investors (proxied by the VIX index in our case) may substantially increase during the crisis, making them shun risky assets and flee into safer assets, particularly, government bonds (Baker et al., 2009; Bekaert et al., 2011).

4. Concluding remarks

This study used the Forbes and Rigobon (2002) correlation test, the Fry et al. (2010) coskewness test, and the Fry-McKibbin and Hsiao (2018) cokurtosis and covolatility tests to examine contagion across European and US financial markets. The 2008 crisis was

417   selected to be the decisive crisis event, while data on bank sector's CDS, insurance sector's

418   CDS, sovereign bond, equity and volatility indices spanning the period 2004 to 2012 were

419   used. Our initial results based on the correlation test show that contagion occurred across

420   financial markets during the global financial crisis, especially through the channels of the

421   insurance and equity sectors. However, higher order moment contagion tests revealed

422   linkages across markets that were not previously detected when using correlation based

423   tests. The additional channels of contagion most prominently supported by the asymmetric

424   and extremal dependence tests were that of the bank and insurance CDS sectors.

425   The empirical findings allow identifying contagion across financial markets and regions

426   and could be helpful for the design of specific stabilization policies. The tests generated

427   results as an additional tool for regulators and policy makers to assess the effectiveness of

428   their policies and the communication of their actions. In particular, our findings carry

429   important implications for investors, policy makers and international organizations, such

430   as International Monetary Fund (IMF), with regard to the linkages among the markets and

431   their real economy sectors. For instance, investors may benefit from the different

432   vulnerability of the markets and real economy sectors, since holding a portfolio with

433   equities from diverse sectors is less subject to systematic risks. From policymakers and

434   international organizations' perspective, the results provided useful information about the

435   directions for possible future policy decisions to protect countries and investors from future

436   financial crises.

437   **References**

438 Acemoglu, D., Ozdaglar, A., Tahbaz-Salehi, A., 2015. Systemic risk and stability in
439 financial networks. American Economic Review, 105, 564-608.
440

441 Acharya, V.V.. 2009. A theory of systemic risk and design of prudential bank regulation.
442 Journal of Financial Stability, 5, 224-255.

443 Acharya, V.V., Yorulmazer, T., 2007. Too many to fail-an analysis of time inconsistency.
444 Journal of Financial Intermediation, 16, 1-31.

445 Acharya, V., Drechsler, I., Schnabl, P., 2014. A pyrrhic victory? Bank bailouts and
446 sovereign credit risk. J. Finance 69, 2689-2739.

447 Adrian, T., Shin, H. S., 2010. Liquidity and leverage. J. Financial Intermedi. 19, 418-437.

448 Allen, F., Carletti, E., 2006. Credit risk transfer and contagion. J. Monet. Econ. 53, 89-111.

449 Allen, F., Gale, D., 2000. Financial contagion. Journal of Political Economy, 108, 1-33.

450 Almeida, H., Campello, M., Laranjeira, B., Weisbenner, S., 2012. Corporate debt maturity
451 and the real effects of the 2007 financial crisis. Critic. Finance Rev. 1, 3-58.

452 Ang, A., Longstaff, F., 2013. Systemic sovereign credit risk: lessons from the U.S. and
453 Europe. J. Monet. Econ. 60, 493–510.

454 Baker, S. R., Bloom, N., Davis, S.J., 2016. Measuring economic policy uncertainty. Quart.
455 J. Econ. 131, 1593-1636.

456 Bartram, S., Bodnar, G., 2009. No place to hide: The global crisis in equity markets in
457 2008/2009. J. Int. Money Finance 28, 1246-1292.

458 Bekaert, G., Harvey, C.R., Lundblad, C.T., Siegel, S., 2011. What segments equity
459 markets? Rev. Financial Stud. 24, 3841-3890.

460 Billio, M., Getmansky, M., Gray, D., Lo, A. W., Merton, R.C., Pelizzon, L., 2014.
461 Sovereign, bank and insurance credit spreads: connectedness and system networks.
462 SYRTO Working Paper No. 8.

463 Black, F., 1972, Capital market equilibrium with restricted borrowing. J. Bus. 45, 444-54.

464 Brunnermeier, M.K., Pedersen, L.H., 2009. Funding liquidity and market liquidity Rev.
465 Financial Stud. 22, 2202-2238.

466 Diamond, D.W., Dybvig, P.H., 1983. Bank runs, deposit insurance and liquidity. Journal
467 of Political Economy, 91, 401-419.

468 Dooley, M., Hutchison, M., 2009. Transmission of the U.S. subprime crisis to emerging
469 markets: evidence on the decoupling–recoupling hypothesis. J. Int. Money Finance 28,
470 1331-1349.

Dornbusch, R., Park, Y.C., Claessens, S., 2000. Contagion: understanding how it spreads. World Bank Res. Obs. 15, 177-97.

Dungey, M., Fry, R., González-Hermosillo, B., Martin, V.L., 2005. Empirical modelling of contagion: a review of methodologies. Quant. Finance 5, 9-24.

Eichengreen, B., Mody, A., Nedeljkovic, M., Sarno, L., 2012. How the Subprime Crisis went global: Evidence from bank credit default swap spreads. J. Int. Money Finance 31, 1299-1318.

Farhi, E., Tirole, J. 2012. Collective moral hazard, maturity mismatch, and systemic bailouts. American Economic Review 102, 60-93.

Forbes, K., 2012. The "Big C": Identifying and mitigating contagion. MIT Sloan School of Management, Working Paper.

Forbes, K., Rigobon, R., 2002. No contagion, only interdependence: measuring stock market comovements. J. Finance 57, 2223-2673.

Freixas, X., Parigi, B., Rochet, J.C., 2000. Systemic risk, interbank relations and liquidity provision by the central bank. Journal of Money, Credit, and Banking 32, 611-638.

Fry, R., Martin, V.L., Tang, C., 2010. A new class of tests of contagion with applications. J. Bus. Econ. Stat. 28, 423-437.

Fry-McKibbin, R., Hsiao, C.Y., 2018. Extremal dependence tests for contagion. Econometric Rev. 37, 626-649.

Fry-McKibbin, R., Hsiao, C.Y., Martin, V.L., 2018. Joint tests of contagion with applications, Quant. Finance 19, 473-490.

Goldstein, M., Kaminsky, G., Reinhart, C., 2000. Assessing financial vulnerability: Developing an early warning system for emerging markets. Institute for International Economics, Washington, D.C.

Gropp, R., Moerman, G., 2004. Measurement of contagion in banks' equity prices, J. Int. Money Finance 23, 405-459.

Haldane, A.G., May, R., 2011. Systemic risk in banking ecosystems. Nature 469, 351-355.

Harvey, C.R., Siddique, A., 2000. Conditional skewness in asset pricing tests, J. Finance 55, 1263-1295.

Hasler, M., Ornthanalai, C., 2018. Fluctuating attention and financial contagion. J. Monet. Econ. 99, 106-123.

Iyer, R., Peydro, J.L., 2011. Interbank contagion at work: evidence from a natural experiment. Review of Financial Studies 24, 1337-1377.

Jorion, P., Zhang, G., 2007. Good and bad credit contagion: Evidence from credit default swaps. J. Financial Econ. 84, 860-883.

506 Jorion, P., Zhang, G., 2009. Credit contagion from counterparty risk. J. Finance 64, 2053-
507 2087.

508 Kallestrup, R., Lando, D., Murgoci, A., 2016. Financial sector linkages and the dynamics
509 of bank and sovereign credit spreads. J. Empir. Finance 38, 374-393.

510 King, M.A., Wadhwani, S., 1990. Transmission of volatility between stock markets. The
511 Rev. Financial Stud. 3, 5-33.

512 Kostakis, A., Muhammad, K., Siganos, A., 2012. Higher co-moments and asset pricing on
513 London Stock Exchange, J. Bank. Finance 36, 913-922.

514 Kraus, A., Litzenberger, R., 1976. Skewness preferences and the valuation of risk assets.
515 J. Finance 31, 1085-1100.

516 Lintner, J., 1965. The valuation of risk assets and the selection of risky investments in stock
517 portfolios and capital budgets. Rev. Econ. Stat. 47, 13-37.

518 Longstaff, F.A., Pan, J., Pedersen, L.H., Singleton, K.J., 2011. How sovereign is sovereign
519 credit risk? Am. Econ. J.: Macroecon. 3, 75-1103.???????

520 May, R.M., Levin, S.A., Sugihara, G., 2008. Ecology for bankers. Nature 451, 893-895.

521 Pan, J., Singleton, K.J., 2008. Default and recovery implicit in the term structure of
522 sovereign CDS spreads. J. Finance 63, 2345-2384.

523 Pericoli, M., Sbracia, M., 2003. A primer on financial contagion. J. Econ. Surveys 17, 571-
524 608.

525 Poti, V., Wang, D., 2010. The coskewness puzzle. J. Bank. Finance 34, 1827-1838.

526 Sharpe, W.F., 1964. Capital asset prices: A theory of market equilibrium under conditions
527 of risk. J. Finance 19, 425-42.

528 Smith, D.R., 2007. Conditional coskewness and asset pricing. J. Empir. Finance 14, 91-
529 119.

530 Tong, H., Wei, S.-J., 2009. The composition matters: capital inflows and liquidity crunch
531 during a global economic crisis. NBER Working Paper 15207, Cambridge, MA.

532 Van Rijckeghem, C., Weder, B., 2001. Sources of contagion: Is it finance or trade? J. Int.
533 Econ. 54, 293-308.

534 Wagner, W.. 2010. Diversification at financial institutions and systemic crises. Journal of
535 Financial Intermediation 19, 373-386.

536
537
538
539
540

541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580

Table 1: The Forbes and Rigobon (2002) $FR(i \rightarrow j)$ correlation-based contagion test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		0.08	3.95	**-7.46**	6.86	3.99	**-5.16**	0.61	**-3.67**	5.10
		(0.53)	(1.00)	**(0.00)**	(1.00)	(1.00)	**(0.00)**	(0.73)	**(0.00)**	(1.00)
EUICDS	**-2.22**		2.73	**-4.20**	3.48	2.36	**-4.21**	0.60	-1.26	2.23
	(0.01)		(1.00)	**(0.00)**	(1.00)	(0.99)	**(0.00)**	(0.73)	(0.10)	(0.99)
EMUGB	2.53	2.69		**-3.26**	2.60	3.18	-1.26	**-3.93**	-1.08	2.75
	(0.99)	(1.00)		**(0.00)**	(1.00)	(1.00)	(0.10)	**(0.00)**	(0.14)	(1.00)

25

EUEQ	**-2.77**	**-1.76**	-0.21		7.37	-1.47	4.12	1.26	-1.51	1.96
	(0.00)	**(0.04)**	(0.42)		(1.00)	(0.07)	(1.00)	(0.90)	(0.07)	(0.98)
EUVOL	4.99	3.24	2.37	3.26		3.07	**-2.30**	0.50	1.04	1.56
	(1.00)	(1.00)	(0.99)	(1.00)		(1.00)	**(0.01)**	(0.69)	(0.85)	(0.94)
USBCDS	3.97	3.49	4.47	**-5.75**	4.73		**-3.01**	4.09	**-4.96**	4.41
	(1.00)	(1.00)	(1.00)	**(0.00)**	(1.00)		**(0.00)**	(1.00)	**(0.00)**	(1.00)
USICDS	**-6.59**	**-5.70**	**-2.36**	4.67	**-3.42**	**-5.52**		**-4.36**	4.69	**-4.33**
	(0.00)	**(0.00)**	**(0.01)**	(1.00)	**(0.00)**	**(0.00)**		**(0.00)**	(1.00)	**(0.00)**
USGB	0.12	0.91	**-3.09**	**-1.69**	1.22	3.36	**-3.60**		-0.38	1.66
	(0.55)	(0.82)	**(0.00)**	**(0.05)**	(0.89)	(1.00)	**(0.00)**		(0.35)	(0.95)
USEQ	-0.72	0.21	0.74	-0.94	3.32	-0.86	3.87	2.31		7.55
	(0.24)	(0.58)	(0.77)	(0.17)	(1.00)	(0.19)	(1.00)	(0.99)		(1.00)
USVOL	4.33	2.69	3.37	**-2.47**	3.01	3.47	**-2.27**	1.67	2.38	
	(1.00)	(1.00)	(1.00)	**(0.01)**	(1.00)	(1.00)	**(0.01)**	(0.95)	(0.99)	

Notes: The $FR(i \rightarrow j)$ test measures contagion from the expected returns of market i to the expected returns of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

581

Table 2.a: The Fry et al. (2010) $CS12$ coskewness-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**1304.96**	1.71	**35.86**	**5.79**	**41.24**	**188.61**	**8.93**	**5.23**	0.81
		(0.00)	(0.19)	**(0.00)**	**(0.02)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.02)**	(0.37)
EUICDS	**413.70**		3.52	**16.43**	1.16	**163.87**	**4.77**	**8.39**	**6.93**	3.43
	(0.00)		(0.06)	**(0.00)**	(0.28)	**(0.00)**	**(0.03)**	**(0.00)**	**(0.01)**	(0.06)
EMUGB	**18.84**	**84.76**		**4.82**	0.21	**79.11**	0.90	**24.94**	0.47	**6.33**
	(0.00)	**(0.00)**		**(0.03)**	(0.64)	**(0.00)**	(0.34)	**(0.00)**	(0.49)	**(0.01)**
EUEQ	**47.46**	**60.92**	3.42		**15.18**	**49.33**	**5.38**	**21.88**	0.27	0.80
	(0.00)	**(0.00)**	(0.06)		**(0.00)**	**(0.00)**	**(0.02)**	**(0.00)**	(0.61)	(0.37)
EUVOL	**54.17**	**103.41**	0.02	**25.53**		**48.29**	**65.39**	2.78	0.05	**7.29**
	(0.00)	**(0.00)**	(0.89)	**(0.00)**		**(0.00)**	**(0.00)**	(0.10)	(0.82)	**(0.01)**
USBCDS	**34.36**	**17.95**	**5.85**	2.18	0.04		**16.50**	**27.99**	**9.88**	2.34
	(0.00)	**(0.00)**	**(0.02)**	(0.14)	(0.83)		**(0.00)**	**(0.00)**	**(0.00)**	(0.13)
USICDS	**32.85**	**52.58**	1.79	0.55	1.71	**146.36**		**25.96**	0.06	0.55
	(0.00)	**(0.00)**	(0.18)	(0.46)	(0.19)	**(0.00)**		**(0.00)**	(0.81)	(0.46)
USGB	**8.84**	1.55	**16.42**	**10.78**	0.81	**174.14**	**58.56**		1.06	0.44
	(0.00)	(0.21)	**(0.00)**	**(0.00)**	(0.37)	**(0.00)**	**(0.00)**		(0.30)	(0.51)
USEQ	**22.84**	**46.98**	**5.53**	**5.98**	1.26	**44.22**	0.45	**29.47**		0.11
	(0.00)	**(0.00)**	**(0.02)**	**(0.01)**	(0.26)	**(0.00)**	(0.50)	**(0.00)**		(0.75)
USVOL	**31.25**	**56.83**	0.00	**4.20**	2.15	**8.97**	3.69	2.14	1.30	
	(0.00)	**(0.00)**	(0.99)	**(0.04)**	(0.14)	**(0.00)**	(0.05)	(0.14)	(0.25)	

Notes: The $CS12$ statistic measures contagion from the expected returns of market i to the volatility of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

583

Table 2.b: The Fry et al. (2010) $CS21$ coskewness-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**396.55**	**18.24**	**42.32**	**51.70**	**34.35**	**32.54**	**8.76**	**21.45**	**30.69**
		(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
EUICDS	**1361.37**		**84.69**	**57.60**	**102.83**	**18.39**	**51.91**	1.56	**45.72**	**57.37**
	(0.00)		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	(0.21)	**(0.00)**	**(0.00)**
EMUGB	1.76	3.52		3.18	0.02	**6.03**	1.78	**16.70**	**5.32**	0.00
	(0.18)	(0.06)		(0.07)	(0.89)	**(0.01)**	(0.18)	**(0.00)**	**(0.02)**	(0.99)
EUEQ	**40.22**	**17.38**	**5.17**		**27.22**	2.41	0.54	**11.48**	**6.05**	**4.61**
	(0.00)	**(0.00)**	**(0.02)**		**(0.00)**	(0.12)	(0.46)	**(0.00)**	**(0.01)**	**(0.03)**
EUVOL	**6.07**	1.16	0.22	**14.25**		0.05	1.69	0.82	1.20	2.21
	(0.01)	(0.28)	(0.64)	**(0.00)**		(0.83)	(0.19)	(0.36)	(0.27)	(0.14)
USBCDS	41.25	159.96	76.84	44.57	46.44		142.25	171.26	40.16	8.77
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)
USICDS	190.42	4.84	0.91	5.40	65.93	16.97		58.75	0.45	3.77
	(0.00)	(0.03)	(0.34)	(0.02)	(0.00)	(0.00)		(0.00)	(0.50)	(0.05)
USGB	9.01	8.35	24.52	20.53	2.73	28.46	25.87		27.85	2.14
	(0.00)	(0.00)	(0.00)	(0.00)	(0.10)	(0.00)	(0.00)		(0.00)	(0.14)
USEQ	5.57	7.12	0.48	0.26	0.05	10.88	0.06	1.12		1.40
	(0.02)	(0.01)	(0.49)	(0.61)	(0.82)	(0.00)	(0.81)	(0.29)		(0.24)
USVOL	0.83	3.40	6.24	0.72	7.09	2.39	0.54	0.44	0.10	
	(0.36)	(0.07)	(0.01)	(0.39)	(0.01)	(0.12)	(0.46)	(0.51)	(0.75)	

Notes: The $CS21$ statistic measures contagion from the volatility of market i to the expected returns of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

585

Table 3.a: The Fry-McKibbin and Hsiao (2018) $CK13$ cokurtosis-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**10205.55**	3.33	**225.57**	**87.79**	**3993.37**	**46997.36**	**229.70**	2.48	**266.04**
		(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.11)	(0.00)
EUICDS	**10.90**		0.05	**302.17**	**88.73**	**5253.58**	**1266.01**	**170.67**	0.20	**151.76**
	(0.00)		(0.83)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.65)	(0.00)
EMUGB	**164.54**	**3211.12**		**13.68**	**10.32**	**3481.81**	**55.63**	**48.76**	**8.15**	**38.43**
	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
EUEQ	**1350.96**	**5.49**	**20.81**		**7.65**	**1252.60**	**6320.21**	**29.55**	**18.24**	1.80
	(0.00)	(0.02)	(0.00)		(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.18)
EUVOL	**636.94**	**934.60**	0.05	0.62		**1058.75**	**16549.73**	**95.17**	**7.99**	**160.18**
	(0.00)	(0.00)	(0.83)	(0.43)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
USBCDS	**720.40**	**555.37**	**128.26**	**55.08**	3.02		**1042.38**	**775.14**	**50.92**	**10.15**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.08)		(0.00)	(0.00)	(0.00)	(0.00)
USICDS	**258.18**	**809.10**	0.79	**23.58**	**5.61**	**3126.96**		**131.41**	**61.31**	**82.75**
	(0.00)	(0.00)	(0.37)	(0.00)	(0.02)	(0.00)		(0.00)	(0.00)	(0.00)
USGB	**39.50**	**1944.80**	**11.63**	0.15	2.28	**5557.75**	**24231.76**		**51.34**	**44.93**
	(0.00)	(0.00)	(0.00)	(0.70)	(0.13)	(0.00)	(0.00)		(0.00)	(0.00)
USEQ	**93.85**	**2793.20**	0.06	**55.22**	**8.13**	**1622.13**	**6.82**	**174.29**		**109.27**
	(0.00)	(0.00)	(0.80)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)		(0.00)
USVOL	**523.22**	**4687.21**	1.52	**53.89**	**3.94**	**555.55**	**216.70**	**129.23**	**4.50**	
	(0.00)	(0.00)	(0.22)	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.03)	

Notes: The $CK13$ statistic measures contagion from the expected returns of market i to the skewness of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

587

Table 3.b: The Fry-McKibbin and Hsiao (2018) $CK31$ cokurtosis-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**4.21**	**125.92**	**914.18**	**520.57**	**719.11**	**308.62**	**45.92**	**40.40**	**477.32**
		(0.04)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
EUICDS	**11006.74**		**3202.82**	**20.46**	**913.11**	**632.08**	**890.84**	**1927.65**	**2849.39**	**4685.86**
	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
EMUGB	0.27	0.07		**4.09**	0.00	**165.01**	**4.83**	**8.27**	2.26	0.43
	(0.60)	(0.80)		(0.04)	(0.98)	(0.00)	(0.03)	(0.00)	(0.13)	(0.51)
EUEQ	**411.81**	**417.99**	**39.94**		**6.70**	**139.91**	**17.65**	**5.62**	**60.84**	**116.37**
	(0.00)	(0.00)	(0.00)		(0.01)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)
EUVOL	**128.75**	**93.91**	**11.70**	0.92		**11.16**	1.07	0.66	1.10	**7.56**
	(0.00)	(0.00)	(0.00)	(0.34)		(0.00)	(0.30)	(0.42)	(0.29)	(0.01)
USBCDS	**3997.72**	**4912.87**	**3196.39**	**863.71**	**908.55**		**2709.77**	**5323.97**	**1184.48**	**503.81**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)
USICDS	**46946.15**	**1171.86**	**38.22**	**6252.11**	**16410.84**	**910.03**		**24068.79**	2.85	**299.40**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.09)	(0.00)
USGB	**216.52**	**178.70**	**55.84**	**61.78**	**107.24**	**834.52**	**152.03**		**226.41**	**129.13**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)
USEQ	1.94	1.27	1.30	**15.41**	1.32	**124.17**	**76.08**	**25.09**		0.03
	(0.16)	(0.26)	(0.25)	(0.00)	(0.25)	(0.00)	(0.00)	(0.00)		(0.87)
USVOL	**298.10**	**138.26**	**30.82**	**16.61**	**173.17**	**6.05**	**126.62**	**45.00**	**142.88**	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	

Notes: The $CK31$ statistic measures contagion from the skewness of market i to the expected returns of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

589

Table 4: The Fry-McKibbin and Hsiao (2018) $CV22$ covolatility-based test results

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		**229.00**	0.13	**523.45**	**319.00**	**1857.76**	0.01	**276.95**	0.00	**240.38**
		(0.00)	(0.71)	**(0.00)**	**(0.00)**	**(0.00)**	(0.90)	**(0.00)**	(0.95)	**(0.00)**
EUICDS	**279.26**		0.11	**127.33**	**74.47**	**2633.59**	**574.22**	**376.03**	**65.34**	1.22
	(0.00)		(0.74)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	(0.27)
EMUGB	1.32	0.13		**5.34**	**5.50**	**743.77**	**318.41**	**32.33**	**15.76**	**6.54**
	(0.25)	(0.72)		**(0.02)**	**(0.02)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.01)**
EUEQ	**794.08**	**174.53**	**17.30**		**6.45**	**150.02**	**216.53**	**14.17**	**26.20**	**47.60**
	(0.00)	**(0.00)**	**(0.00)**		**(0.01)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
EUVOL	**389.99**	**77.52**	**6.16**	0.68		**213.37**	1.27	**35.46**	**7.94**	**13.08**
	(0.00)	**(0.00)**	**(0.01)**	(0.41)		**(0.00)**	(0.26)	**(0.00)**	**(0.00)**	**(0.00)**
USBCDS	**1858.34**	**2572.81**	**740.16**	**180.83**	**224.61**		**2023.26**	**3433.33**	**649.03**	**119.23**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
USICDS	0.01	**573.38**	**316.83**	**215.52**	0.89	**2068.64**		**126.80**	**306.08**	**143.90**
	(0.92)	**(0.00)**	**(0.00)**	**(0.00)**	(0.34)	**(0.00)**		**(0.00)**	**(0.00)**	**(0.00)**
USGB	**274.92**	**376.86**	**36.24**	**25.05**	**38.78**	**3495.05**	**127.69**		**112.18**	**37.01**
	(0.00)	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**	**(0.00)**
USEQ	2.03	**58.60**	**10.34**	**23.10**	3.09	**643.57**	**307.73**	**95.13**		**17.57**
	(0.15)	**(0.00)**	**(0.00)**	**(0.00)**	(0.08)	**(0.00)**	**(0.00)**	**(0.00)**		**(0.00)**
USVOL	**261.98**	1.72	**4.82**	**17.70**	**17.70**	**112.47**	**150.35**	**37.04**	**34.44**	
	(0.00)	(0.19)	**(0.03)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	

Notes: The $CV22$ statistic measures contagion from the volatility of market i to the volatility of market j. The first column indicates the source market, while the first row indicates the recipient market. The null hypothesis is "no contagion". The figures denote the test statistics values, while those in parenthesis are the p-values. Figures in bold indicate the rejection of the null hypothesis at the 5% significance level. EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

591

Appendix

Table A1: Sources of the financial sector indices

		Europe			United States	
Equity Index	EUEQ	EURO STOXX 50 Index (DJES50I)		USEQ	S&P 500 Index (S&PCOMP)	
Volatility Index	EUVOL	EURO STOXX 50 Volatility Index (VSTOXXI)		USVOL	CBOE Volatility Index (VIX) (CBOEVIX)	
Sovereign Bond Index	EMUGB	EMU Benchmark 5 yr. DS Gov. Index (BMEM05Y)		USGB	US Benchmark 5 yr. DS Gov. Index (BMUS05Y)	
Bank Sector CDS Index	EUBCDS	EU Bank Sector 5 yr. DS CDS Index (EUBANCD)		USBCDS	US Bank Sector 5 yr. DS CDS Index (USBANCD)	
Insurance Sector CDS Index	EUICDS	EU Insur. Sector 5 yr. DS CDS Index (EUINSCD)		USICDS	US Insur. Sector 5 yr. DS CDS Index (USINSCD)	

Notes: The code inside the bracket below the name of the index indicates the Datastream mnemonic of the index.

596

Table A.9b Descriptive statistics

Descriptive statistics for the pre-crisis period									
	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
Mean	0.00249	0.00129	-0.00001	0.00012	0.00067	0.00249	0.00236	0.00003	0.00005	0.00081
Std. Dev.	0.03597	0.04119	0.00184	0.01029	0.05218	0.05184	0.04092	0.00270	0.00901	0.06294
Skewness	1.08343	2.15014	-0.00364	-0.44000	0.86925	-1.29980	0.37288	0.11097	-0.35873	0.70450
Kurtosis	13.52152	30.95665	4.46548	8.23201	6.10058	31.48781	10.81201	6.21038	5.92657	8.84771

Pre-crisis period correlation

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		0.72234	0.25889	-0.27970	0.22759	0.25855	0.47809	0.16923	-0.11494	0.07295
EUICDS	0.72234		0.21822	-0.24623	0.24796	0.23395	0.44325	0.14435	-0.12052	0.10481
EMUGB	0.25889	0.21822		-0.41113	0.33382	0.23485	0.21193	0.57167	-0.25156	0.18963
EUEQ	-0.27970	-0.24623	-0.41113		-0.81312	-0.31983	-0.29414	-0.31168	0.48355	-0.40025
EUVOL	0.22759	0.24796	0.33382	-0.81312		0.26928	0.24540	0.26541	-0.43123	0.45215
USBCDS	0.25855	0.23395	0.23485	-0.31983	0.26928		0.41385	0.20792	-0.30103	0.24239
USICDS	0.47809	0.44325	0.21193	-0.29414	0.24540	0.41385		0.21967	-0.27450	0.22736
USGB	0.16923	0.14435	0.57167	-0.31168	0.26541	0.20792	0.21967		-0.39973	0.30151
USEQ	-0.11494	-0.12052	-0.25156	0.48355	-0.43123	-0.30103	-0.27450	-0.39973		-0.80914
USVOL	0.07295	0.10481	0.18963	-0.40025	0.45215	0.24239	0.22736	0.30151	-0.80914	

Descriptive statistics for the crisis period

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
Mean	0.00067	0.00011	0.00017	-0.00019	-0.00042	-0.00082	-0.00067	0.00015	0.00020	-0.00075
Std. Dev.	0.04019	0.04564	0.00236	0.01867	0.06374	0.05409	0.09494	0.00323	0.01715	0.07185
Skewness	-0.15719	-5.37533	-0.03285	0.13490	0.78845	0.02789	-13.31658	-0.14018	-0.26795	0.71784
Kurtosis	22.51380	92.85061	4.46621	7.18374	5.95402	24.86864	343.39414	8.29233	10.25302	6.62651

Crisis period correlation

	EUBCDS	EUICDS	EMUGB	EUEQ	EUVOL	USBCDS	USICDS	USGB	USEQ	USVOL
EUBCDS		0.60832	0.36477	-0.44636	0.40099	0.32821	0.11397	0.22223	-0.27716	0.30077
EUICDS	0.60832		0.36786	-0.45636	0.40668	0.32986	0.16366	0.23029	-0.29239	0.29589
EMUGB	0.36477	0.36786		-0.57288	0.49242	0.36373	0.15568	0.51138	-0.37422	0.37924
EUEQ	-0.44636	-0.45636	-0.57288		-0.77119	-0.50831	-0.17755	-0.39571	0.66127	-0.56285
EUVOL	0.40099	0.40668	0.49242	-0.77119		0.43517	0.16356	0.31991	-0.46778	0.60427
USBCDS	0.32821	0.32986	0.36373	-0.50831	0.43517		0.20890	0.33023	-0.45004	0.44172
USICDS	0.11397	0.16366	0.15568	-0.17755	0.16356	0.20890		0.09676	-0.16462	0.18187
USGB	0.22223	0.23029	0.51138	-0.39571	0.31991	0.33023	0.09676		-0.40409	0.36259
USEQ	-0.27716	-0.29239	-0.37422	0.66127	-0.46778	-0.45004	-0.16462	-0.40409		-0.76845
USVOL	0.30077	0.29589	0.37924	-0.56285	0.60427	0.44172	0.18187	0.36259	-0.76845	

Notes: EUBCDS, USBCDS and EUICDS, USICDS are the European and US bank sector CDS indices, and the European and US insurance sector CDS indices, respectively. EMUGB and USGB are the EMU and the US sovereign bond indices. EUEQ, USEQ and EUVOL, USVOL are the European and US equity and volatility indices, respectively.

597