Contagion in CDS, Banking and Equity Markets[☆]

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Abstract

We develop an endogenous testing strategy for finding contagion within stock markets indices, Credit Default Swaps spreads and banking sector indices. We present evidence of strong contagion in specific cases and markets and show an analysis of contagion to Brazil. Our results are important for the development of macro-prudential policies.

Keywords: Contagion; Emerging Markets; Correlation; Coskewness; Endogenous Testing.

JEL codes: G01; G15.

[☆] The opinions expressed here are those of the authors and do not necessarily represent neither those of the Banco de Central do Brasil nor of its Board of Directors. As usual, all errors and omissions in this work are the responsibility of the authors.

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1. Introduction

The study of financial contagion is becoming increasingly relevant as financial crises such as the Global Financial Crisis[1], and the European Sovereign Debt Crisis[2] had their effects spread throughout the world. The understanding of changes in the volatility of worldwide financial markets, the way such changes spread and its impact on the financial stability has become of great importance for governments and regulatory agencies.

There is an increasing number of works that are concerned with financial contagion due to the recent crises. Bengtsson [11] studies the Global Financial Crisis and its impact in the European MMF industry. This paper discuss the effects of this contagion channel in the European economy and its influence in the financial instability that reached Europe from 2007. Analyzing fluctuations in the sovereign risk of the countries that belong to their sample, Beirne and Fratzscher [9] examine the effects of the European Sovereign Debt Crisis in various economies. Their work covers 31 countries, which mostly presented contagion evidence.

In this paper we aim to develop a framework for the analysis of contagion in the recent crises which does not require a previously defined dating of a crisis period. Our study includes an empirical analysis of the most affected countries due to financial instability in the Global Financial Crisis and the European Sovereign Debt Crisis and a more detailed presentation of the contagion to the Brazilian economy.

Contagion tests such as those developed by Forbes and Rigobon [27] and Fry et al. [28] compare a previously defined "crisis period" with a "tranquil period" and find contagion through statistically significant structural breaks. The proper choice of those periods are generally regarded as "an essential component" (Hsiao et al. [32]). However in the literature those two periods are usually defined exogenously from the model, with the boundaries gathered from some general consensus, which identifies certain events with the start and end of a crisis. We believe that such arbitrary dating may be hiding patterns in contagion effects that would be interesting to study. Also it is our understanding that in many crises this arbitrary dating may not be easy or even possible to make with any precision.

Because of this difficulty in defining the proper dating of each crisis, we propose a contagion test which does not rely on exogenous definition of contagion dates, but uses the same testing framework as the tests developed by Forbes and Rigobon [27] and Fry et al. [28]. For such ends an endogenous search for contagion is proposed in which a window is moved along all possible dates and each window is tested for contagion. The results of all tests are gathered and analysed.

We have apply this endogenous search to both the Global Financial Crisis and the ongoing European Sovereign Debt Crisis and find evidence of contagion consistent with general consensus of the contagion periods. A special study is done on the evidence of contagion to Brazil.

The remainder of this paper is structured as follows: section 2 reviews current literature on contagion measurements, section 3 describes the datasets used in this paper, section 4 describes the contagion measurement tests developed by Forbes and Rigobon [27] and Fry et al. [28] used in this paper, section 5 outlines our proposal for endogenous contagion tests, 6 presents the results and a commentary, and section 7 concludes the paper.

[1] The crisis which started with the collapse of the subprime market in the USA in 2007.

[2] The crisis that started in late 2009 with the discovery of the fiscal problems of the Greek government and is still under way.

2. Literature review

There is a growing body of literature on the topic of financial contagion. We mostly find studies related to this subject using the correlation tests created by Forbes and Rigobon [27] and Fry et al. [28]. However, there are papers that develop alternative approaches to examine contagion channels, for example, Manz [38] and Castiglionesi [14]. Manz [38] explores a global game model of information-based financial contagion, where the failure of a single firm can trigger the failure of another. Castiglionesi [14] investigates the impact of a central bank intervention in preventing financial contagion. Thus, we present the Tables 1 and 2 to provide a summary of the contributions related to this topic.

< Place Tables 1 and 2 About Here. >

Overall we can infer from this literature that there are various competing models and approaches to test for contagion. For the purposes of this paper, the main method is the one proposed by Forbes and Rigobbon which looks for structural breaks in correlations between markets, with proper adjustments for heteroscedasc-ity. This method was further developed by Fry et al. [28] including an important addition as it proposes a framework for contagion tests in higher-order moments of the distribution.

Despite the recent developments in the financial contagion literature, there seems to be a gap regarding the definition of the sample to be tested. Mandilaras and Bird [37] contribute to this puzzle performing a contagion analysis using a Markov-switching vector autoregression to determine the crisis and non-crisis observations. However, the question still remains: How long should be periods before and after contagion? Thus, our main contribution is the proposal of a search for contagion while the dating of the contagion period is endogenously set since the crisis and pre-crisis periods are usually defined exogenously and arbitrarily for each crisis.

3. Data

In this paper we perform endogenous tests for contagion through three distinct channels or dimensions: the equity market, the banking system and the sovereign CDS[3] market. Testing for contagion in different channels allows for a better characterization of how a given crisis might have affected a country, and also help in pointing the direction for finer-grained studies.

The rationale for the choice of channels is as follows. Contagion in CDS spreads indicates that during a crisis, the market expects it to trigger a rise in the country's probability of default, and therefore a decrease in its ability to finance itself and pay its debts. Contagion in the banking sector reflects a loss of capital or of funding in the affected country's banking system. Contagion in the equity market indicates an increased risk aversion in investors and less availability of funding for listed companies in that specific country.

For the country equity market we used the MSCI standard country index. For CDS spreads, Thomson Reuters Sovereign CDS. For the banking sector, Data Stream Bank Sector index. We used the daily US Federal Funds Rate and Commodities CRB Total Return index for controlling for fundamentals. All data was obtained through Datastream.

[3]Credit Default Swaps.

We calculate the descriptive statistics of each series for three different periods: the whole period from January 2006 to October 2011 (the full period), from January 2008 to October 2011 (the Global Financial Crisis period), and from December 2009 to October 2011 (the European Sovereign Debt Crisis). The effects of the Global Financial Crisis are visible in the volatility in the 2008 to 2011 period, which is generally higher than in the full period (the volatility is higher in 49 out of 54 countries), however if the periods of the European Sovereign Debt Crisis is compared to the period of Global Financial Crisis, only four countries have their volatility increased, namely Greece, Portugal (two of the countries central to the European Sovereign Debt Crisis), Indonesia and Venezuela.

Regarding skewness, 39 countries have their skewness increased in the subprime period relative to the full period, and 30 countries have their skewness increased in the European crisis period, including 17 European countries. According to Kraus and Litzenberger [34] this higher skewness signals an increase in risk aversion, and is important for one of the tests used in this paper as described in section 4.

The descriptive statistics of the MSCI equity indexes are similar to those of the banking sector, and the same analysis applies, but the CDS spreads are different. The first difference is that the sample data begins at December 2007 and therefore in the CDS spreads case the period from January 2008 to October 2011 is regarded as the full period. Also, the volatility increases in many more countries in the two periods of the European Sovereign Debt Crisis.[4]

4. Contagion testing

In our paper we adopt the same definition of contagion as that of Forbes and Rigobon [27]:"*a significant increase in cross-market linkages after a shock to one country (or group of countries)*". This definition is formal enough for statistical testing and is broad enough to signal various forms of contagion. Given this definition we consider three possible measures of contagion. One based on correlation, and two based on coskewness.

The logic of contagion tests based on correlation is that during a crisis contagion from one market to another is signalled is through a significant increase in the correlation of these markets. That is, if the prices of one market fall, the prices of the the other also fall in a way that is stronger than predicted by their expected co-movements. Regarding correlation tests for contagion, Forbes and Rigobon [27] observe that the higher volatility in times of crisis tends to increase the correlation coefficients and therefore bias the contagion tests towards false positives, and thus a better correlation-based test should take this into account. Fry et al. [28] develop the final form of the correlation-based contagion test used in this paper, which we call the *FR* test.

The coskewness test are derived from an extension to the CAPM model due to Kraus and Litzenberger [34], which incorporates skewness, and a further development by Harvey and Siddique [31] which refined this model to include conditional skewness. Both argues that risk aversion in a CAPM model which incorporates skewness implies a preference for positive skewness. That is, a risk averse investor will seek assets that increase the coskewness of a portfolio. On the other hand, in order to add an asset to its portfolio that impacts its skewness negatively, the risk averse investor will demand higher returns. Based on this observation, Fry et al. [28] argued that another signal of a crisis would be a shift towards positive skewness as risk averse

[4]The descriptive statistics tables of all markets were removed from the paper for space purposes. The authors can provide them upon request.

investors trade off smaller returns for positive skewness. From this observation , Fry et al. [28] developed two coskewness based tests, *CS1* and *CS2*, which build on the *FR* test. Both tests aim to identify significant changes in coskewness between the periods before a crisis and during a crisis.

The *CS1* test for contagion verifies whether there is a significant decrease in the source market returns and a related increase the volatility in the second market. This implies that the crisis in the source market has been identified with positive skewness (investors are seeking safer assets and accepting lower returns), and the second market suffers contagion in the form of higher volatility.

The *CS2* test for contagion verifies whether there is a significant increase in volatility in the source market and a significant decrease of the average returns in the second market, that is, the higher volatility in the source market affects investors in the second market, which turn to safer assets (smaller returns) seeking positive skewness.

4.1. Contagion tests

In order to test for the occurrence of contagion from one market to another, we separate each series i and j into a pre-crisis and a crisis period, and then compare the joint behaviour of i and j. If the resulting statistic is greater than a critical value, there is indication of contagion.

The first statistic (which in this paper is identified by *FR*) tests for an increase in the correlation of the two series in the crisis period. The second and third statistics (in this paper, *CS1* and *CS2*) test for an increase in volatility in j and smaller returns in i (*CS1*), and for smaller returns in j and increased volatility in i (*CS2*).

4.2. Correlation Contagion testing

The correlation-based testing for contagion used in this paper follows the proposal by Forbes and Rigobon [27] and further refined by Fry et al. [28].

Let ρ_c and ρ_{pre} be the correlations between i and j in the crisis and pre-crisis periods. The correlation of the crisis period is adjusted for the greater volatility of the crisis period as per Forbes and Rigobon [27], and the adjusted correlation ν_c is then used for the calculation of the *FR* statistic:

$$\nu_c = \frac{\rho_c}{\sqrt{1+\delta(1-\rho_c^2)}}, \tag{1}$$

$$\delta = \frac{s_{c,i}^2 - s_{pre,i}^2}{s_{pre,i}^2}, \tag{2}$$

where $s_{c,i}^2$ and $s_{pre,i}^2$ are the variances of i in the crisis and pre-crisis periods. Let T_c be the number of observations in the crisis period and T_{pre} the number of observation in the pre-crisis period.

$$FR(i \to j) = \left(\frac{\nu_c - \rho_{pre}}{\sqrt{Var(\nu_c - \rho_{pre})}} \right)^2, \tag{3}$$

where

$$Var(\nu_c - \rho_{pre}) = Var(\nu_c) + Var(\rho_{pre}) - 2Cov(\nu_c, \rho_{pre}), \tag{4}$$

$$Var(\nu_c) = \frac{1}{2}\frac{(1+\delta)^2}{[1+\delta(1-\rho_c^2)]^3}\left[\frac{1}{T_c}\left((2-\rho_c^2)(1-\rho_c^2)^2\right) + \frac{1}{T_{pre}}\left(\rho_c^2(1-\rho_c^2)^2\right)\right], \tag{5}$$

$$Var(\rho_{pre}) = \frac{1}{T_{pre}}(1-\rho_{pre}^2)^2, \tag{6}$$

$$Cov(\nu_c, \rho_{pre}) = \frac{1}{2}\frac{1}{T_{pre}}\frac{\rho_c\rho_{pre}(1-\rho_c^2)(1-\rho_{pre}^2)(1+\delta)}{\sqrt{[1+\delta(1-\rho_c^2)]^3}}. \tag{7}$$

Under the null hypothesis of no contagion, the two-tailed adjusted correlation test is asymptotically distributed χ_1^2. Although the test is two-tailed, this paper only concerns itself with increases in correlations, therefore the test indicates contagion only if $FR(i \rightarrow j)$ is greater than some critical value in χ_1^2 and $\nu_c > \rho_{pre}$.

4.3. Coskewness contagion testing

Fry et al. [28] propose coskewness tests for contagion, which identifies contagion from the value of i to the volatility of j and from the volatility of i to the value of j.

Let $\hat{\mu}_{T,k}$ the mean of k in period T and $\hat{\sigma}_{T,k}$ the standard deviation of k in T, where T can be either T_c ou T_{pre} and k can be either i or j.

The coskewness contagion test from i to the volatility of j, $CS_1(i \rightarrow j; i^1, j^2)$, and the coskewness contagion test from the volatility of i to j, $CS_2(i \rightarrow j; i^2, j^1)$ are given by:

$$CS_1(i \rightarrow j; i^1, j^2) = \left(\frac{\psi_c(i^1, j^2) - \psi_{pre}(i^1, j^2)}{\sqrt{\frac{4\nu_c+2}{T_c} + \frac{4\rho_{pre}^2+2}{T_{pre}}}}\right)^2, \tag{8}$$

$$CS_2(i \rightarrow j; i^2, j^1) = \left(\frac{\psi_c(i^2, j^1) - \psi_{pre}(i^2, j^1)}{\sqrt{\frac{4\nu_c+2}{T_c} + \frac{4\rho_{pre}^2+2}{T_{pre}}}}\right)^2, \tag{9}$$

where

$$\psi_c(i^m, j^n) = \frac{1}{T_c}\sum_{t=1}^{T_c}\left(\frac{i_t - \hat{\mu}_{c,i}}{\hat{\sigma}_{c,i}}\right)^m\left(\frac{j_t - \hat{\mu}_{c,j}}{\hat{\sigma}_{c,j}}\right)^n, \tag{10}$$

$$\psi_{pre}(i^m, j^n) = \frac{1}{T_{pre}}\sum_{t=1}^{T_{pre}}\left(\frac{i_t - \hat{\mu}_{pre,i}}{\hat{\sigma}_{pre,i}}\right)^m\left(\frac{j_t - \hat{\mu}_{pre,j}}{\hat{\sigma}_{pre,j}}\right)^n. \tag{11}$$

Under the null hypothesis of no contagion, the two-tailed adjusted correlation test is asymptotically distributed χ_1^2.

5. Endogenous test for contagion

In section 4.2 we presented contagion tests based on the structural break of some property of a distribution. Those tests require the definition of two periods in the series that are being tested, a crisis period and a pre-crisis period. However the proper dating of the crisis and pre-crisis period can be difficult. Even when it is possible to identify the start of a crisis more easily, the choice of its end may not be so clear. In addition, a crisis may have recurring critical events, and multiple rounds of contagion, or there might be many sources of contagion, and the contagion from each source may be stronger at different dates.

Instead of an exogenously defined crisis and pre-crisis periods, in this paper we define test windows over the entire period, test each window for contagion and then consolidate the results, looking for the dates of the windows where the contagion statistics are higher than a critical value. For additional robustness checks,

we define multiple window sizes. In this way we overcome the problem of crisis dating through endogenous testing.

Given the series we are testing for contagion, we define a fixed length window and move it across the sample. Each window consists of a pre-crisis period — which for this paper was set to two years — and a crisis period — which for robustness testing was defined to be of three lengths: 4, 6 and 8 months. Each window starts one week after the previous window's start. We did this for each pair of markets i and j in each test dimension (country equity, sovereign CDS, bank equity indexes).

We test each window by estimating a Vector Auto Regressive (VAR) model of the source and destination market in each period (crisis and pre-crisis), controlling for the pre-defined exogenous variables (US Federal Funds rate and Commodities index). Each VAR is calculated with a fixed lag of 5 observations in order to eliminate residual autocorrelation. We then test the *residuals* for contagion as described in section 4. The result is a set of statistics for that particular test instance $T_{i,j,D,W,L}$(where i is the source market, j the destination market, D the dimension being tested, W the period window, and L the crisis window length). Such test instance is said to be an instance of contagion if the following conditions are met:

- The volatility of the crisis period residuals must be greater than that of the pre-crisis period.
- For the FR statistic, the correlation of the crisis period residuals must be greater than that of the pre-crisis period (we are only testing one tail of the distribution).
- The tests results (Forbes-Riggobon correlation, CoSkewness Testing in both directions) must be greater than a pre-established critical value (in this paper, 5.9915, which is the critical value for the χ^2 distribution at 95% confidence and 2 degrees of freedom).

These instances of contagion which meet all conditions above are all points in time at which there was a structural break in the relationship of pairs of markets (be it correlation of coskewness). The next step is the endogenous choice of contagion periods. We opted to include all contagion periods in our analysis of results, as the aim of this paper is to validate a method for finding the periods of contagion through endogenous testing.

6. Empirical results

The empirical tests generated large volumes of data. The total number of contagion tests for analysis was $750,013$, including 3 windows sizes, and three contagion channels (bank, equity, CDS), each having its own sample size and represented countries. We have chosen to present the results in graphs with an accompanying analysis.

The results will be presented as follows: first, general contagion results, involving all countries, are presented for each crisis, and then a more detailed analysis of the contagion to Brazil is presented. The empirical results have shown that even in absence of precise dating, the fixed-length moving window tests were capable of identifying the most significant periods of contagion, which is further corroborated by the fact that in most cases tests with different contagion windows agree with each other.

We present two types of graphs for visualization. Both follow a common logic: we show the evolution of the relevant indexes (normalized towards each index initial value) and draw shaded areas to indicate contagion according to a color scale. The shaded areas indicate the strength of the contagion statistic in window that starts at each date. The difference in the graph types is the meaning of the strength of contagion in the graph. In the general contagion graphs (in which contagion to all countries is summarized), the strength of contagion is the number of different countries for which the relevant statistic indicates contagion[5] at that date. The second type is the localized contagion to Brazil, in which case the strength of contagion is the value of the statistic, bearing in mind that only values above the certain critical value[6] are represented.

Most of the events that were referred to in the following analyses can be found in US Federal Reserve [49], Deutsche Bundesbank [19, 20], European Central Bank [24] and US Federal Reserve St Louis [50]. We also use the study of Dwyer and Tkac [23] to justify some of our next arguments about the Global Financial Crisis. This paper presents a precise description of the problems that the US fixed-income market faced in this crisis.

[5] Contagion, in this paper, is indicated as a structural break in a statistic.
[6] See section 5.

6.1. General contagion

6.1.1. The Global Financial Crisis

Our tests for contagion through the banking sector show evidence of contagion in the banking sector indexes throughout 2008 and into early 2009. These results are shown graphically in figures 1, 2 and 3. Most of this contagion is detected through structural breaks in coskewness, but both coskewness tests are consistent with each other regarding countries affected and the contagion periods (with the *CS2* statistic detecting more instances of contagion). The results identify occurrences of contagion from the USA to fifty-one countries (out of fifty-three) at some time in this period. The results are also consistent across all contagion window sizes tested (four, six and eight months).

The number of countries affected in a single week peaks at 30 (from the *CS2* test, 25 from *CS1* test) in late February, and early March, which is consistent with the increasing uncertainty fueled by events such as the collapse of the subprime mortgage market stemming up to 400 billion dollars in losses (February 10th) and the nationalization of the Northern Rock (February 17h). This uncertainty persisted in spite of actions by the Federal Reserve and other Central Banks beginning in December 2007 trying to increase liquidity available to banks, culminating with a fund of 200 billion dollars made available to banks by the US Federal Reserve (March 7th). After this period, the number of countries simultaneously affected by contagion drops, and raises again to 26 countries (from the *CS1* test, 19 from *CS2* test) in late September and early October as great uncertainty returns in the wake of the Lehman Brothers bank filling for bankruptcy and the increasing instability in the European banking sector. These results are shown graphically in figures 1, 2 and 3.

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The results for contagion in the MSCI equity indexes are shown graphically in figures 4, 5 and 6. The tests for contagion through equity also show ample contagion throughout 2008, where 58 countries out of 66 tested positive for contagion, however the contagion stops at a earlier date in 2009 than in the banking sector indexes, and at an even earlier date (December 2008) in the tests with larger windows (6 and 8 months), which indicates that the general equity market begins its recovery faster than the banking sector. There is one other significant difference from the banking sector contagion in that most of the early contagion (in early 2008) is in the tests with 8-month contagion windows, and also increases in the 6-month and 4-month contagion windows as their end dates reach the year's fourth quarter. This indicates that for the general equity markets, as opposed to banks, the bulk of the contagion is concentrated at the end of each contagion period, related to the events of September and October (the Lehman collapse, the nationalization and partial nationalization of European funds, the bail out funds approved by the US and European governments).

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6.1.2. The European Sovereign Debt Crisis

Regarding the European Sovereign Debt Crisis, we tested for contagion originating from the following countries: Portugal, Greece, Ireland, Italy and Spain. These countries are at the forefront of most stories on the ongoing crisis. Also in accordance to most coverage, the contagion tests for the European Debt Crisis have indicated two clearly distinct periods of contagion, the first in early 2010 and the second in late 2011.

The banking sector tests suggest that contagion in the European Sovereign Debt Crisis is as widespread as in the Global Financial Crisis. In the first contagion period 46 out of 49 tested countries are affected by contagion, and 48 countries in the second period. One difference from the subprime crisis is that the *FR* tests are relevant, indicating contagion to 18 countries in both periods. The results of the *FR* tests as well as the *CS1* and *CS2* are show in figures 7, 8, 9, 10, 11 and 12.

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In the first period contagion is stronger starting from January 2010, reaching up to 38 countries (from the *CS2* test, 26 from *CS1* test). The *FR* tests find most contagion around late march through late April, with up 18 countries affected at the same time. The epicenters of this first period seem to be the uncertainty caused by the large Greek budget deficit, and downgrades in ratings of the Greek (starting in December, 2009), Portuguese and Spanish debts (April 2010). By May, 2010 the European Union agrees on a 750 billion dollars bailout plan and no new instances of contagion are found until the second period. This suggests that such tests may be helpful in assessing whether specific policies that are being undertaken are effective. Initially it seems to be the case, for beginning in May, 2010 both the MSCI and bank sector indexes for most of the source countries show a limited recovery. However by late 2010 and early 2011 they drop once again and the second period of contagion begins.

The second period is different from the first in that the most contagion is most relevant at the end of each window, as evidenced by how the contagion windows starting dates are aligned about 2 months apart, first the 8-month contagion windows, then the 6-month windows and finally the 4-months windows. All of the contagion periods shown end in October 31^{th}, 2011, which is the last date of the sample period in this study. This is consistent with the stronger drops in the MSCI and bank sector indexes of the source countries (and the rise in CDS spreads for their debts), and also with events such as the resignation of Portugal's Prime Minister (March 2011), Portugal's request for financial support from the European Union (April 2011) and its ratings downgrades, the further downgrade of Greece's and Ireland's debts, and the increasing uncertainty regarding Italy (which had its debt rating downgraded in September) and Spain, both having to increase the yields on government issued bonds.

The equity indexes show a very similar picture, with similar contagion strength at similar dates. This indicates that unlike the subprime crisis, in which the bank sector is hit first and then the equity market, in the European crisis both markets suffer contagion at the same time. The only significant difference is in *FR* tests. In the bank sector most instances of contagion are in the first period, while in the equity market they are stronger in the second period of the crisis.

The analysis of the CDS spreads also divides the crisis into two periods, with slightly different timing. In the first period, the contagion peak is in early May 2010 as CDS spreads start to rise. Throughout the two crisis periods, 35 countries suffered contagion in their CDS spreads according to the *FR* tests. The results for the CDS tests are show in figure 13.

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It seems to us that contagion tests can be an important tool for regulators and policy makers to assess the effectiveness of their policies and of the communication of their actions.

6.2. Contagion to Brazil

The tests find evidence of contagion to Brazil in both the Global Financial Crisis and the European Sovereign Debt Crisis. Of particular note is that most contagion is found through the coskewness test, although there is also correlation-based contagion from Greece to Brazil in the CDS spreads in 2010.

6.2.1. Global financial crisis 2008

Brazil is one of the countries affected by the Global Financial Crisis. The results of the contagion tests to Brazil show evidence of contagion both in the bank sector and in the general equity indexes. The first signals of contagion are detected in the bank sector indexes. The figure 14 shows the results of the contagion tests from the USA to Brazil, which are detected through the *CS2* test with windows of 4, 6 and 8 months. We do not find any contagion to Brazil applying *FR* and *CS1* tests for the bank sector indexes. The contagion identified starts in the period from February 1, 2008 to June 13, 2008.

For the 4-month window contagion test, the peak statistic occurs in the period of March 21 2008 to July 21 2008, when the *CS2* statistic is 22.54. Both the 6-month and the 8-month window tests have their peak starting in February 2, 2008, with the 6-month window ending in August, 2008 and the 8-month window ending in October, 2008. Both windows overlap the peak 4-month window. From the tests results as shown on figure 14 we can observe that the 4, 6 and 8-month *CS2* tests possess similar findings, with many test instances overlapping, and some intervals when the contagion results do not match exactly between the three tests. The 6 and 8-month windows have both the most overlaps and the highest statistics, with the strongest values in windows which start in February and run at least until August, 2008.

The fact that the contagion is detected only in the *CS2* statistic is significant, as it signals increasing risk aversion (and therefore lower average returns) because of the higher volatility in the US banking sector. In January 2008 the U.S. Federal Reserve rates had a decrease of three quarters of a percentage point, which was the biggest cut in 25 years, bringing the value down to 3.5%, and the major bond insurer Municipal Bond Insurance Association (MBIA) announced $ 2.3 billions in losses. In February 10, 2008 the at G7 meeting it was announced an estimated $ 400 billions in losses due to the collapse of the subprime mortgage market.

In March 7^{th} 2008 the U.S. Federal Reserve injected $200 billions to increase the liquidity of U.S. economy, which was another signal of an unstable financial environment. In March 16^{th} 2008, J.P. Morgan Chase buys the Bear Sterns in a deal backed up by the U.S. government. As the instability grew, risk aversion

motivated investors to seek positive skewness, which can account for the contagion to the Brazilian banking sector throughout February and March.

< Place Figure 14 About Here. >

The contagion analysis of the MSCI equity indexes also show contagion to Brazil from the *CS1* and *CS2* tests. The results are shown in the figures 15 and 16. The first observation from these graphs is that while our tests detect contagion in the bank sector starting February, 2008, most contagion detected in the equity market starts a few months later, becoming stronger after September, 2008, with the levels of contagion statistics rising sharply after September 19th and peaking in early October, 2008.

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By May 2008, the worldwide financial market already faces an unstable environment and this state is sustained during the following months. In July 11^{th} the American Federal regulators seize IndyMac Bank due to the reduced liquidity that U.S. economy faces, while the barrel of oil reaches a record price of $147.5. In July 14^{th} 2008, the American Financial authorities decide to assist Fannie Mae and Freddie Mac. These government sponsored agencies have a total debt of $5 trillion and are helped by American government as they are considered crucial to the U.S. housing market. September 2008 is a month of highly significant events that brought about further instability in the worldwide financial markets. In September 15^{th}, 2008, the Lehman Brothers announces its filing for bankruptcy. This single event is identified as the "trigger event" of the Global Financial Crisis in some of the contagion literature (as in Fry et al. [28], [22]). We believe that the growing instability leading to the collapse of the Lehmann Brothers, and the greater instability that follows may explain the contagion to the Brazilian economy.

We note that for the Global Financial Crisis, our tests indicate early contagion in the banking sector, which is followed a few months later by the contagion in the general equity market, which is stronger after the collapse of the Lehmann Brothers.

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6.2.2. European sovereign debt crisis 2010/2011

Our tests indicate contagion from the European Sovereign Debt Crisis to Brazil. Most of the contagion to Brazil detected by the tests is from Portugal and Spain, with additional contagion from Italy and Greece. We find coskewness contagion (*CS1* and *CS2*) in both bank sector and equity market indexes, and correlation contagion (*FR*) in the CDS spreads. Regarding the occurrences of contagion, our tests break the European Sovereign Debt Crisis into two major periods: early 2010 and mid to late 2011. The graphs with results for the contagion tests in the bank market are shown in figures 17 and 18.

< Place Figures 17 and 18 About Here. >

Most contagion to Brazil is concentrated in early 2010. Coskewness contagion from Portugal and Spain is detected in the bank sector indexes from January through late April (early May for the *CS2* tests) in 2010. The *CS1* tests detect contagion mostly through the 6 and 8-month window tests, with some periods of contagion in all three window lengths, while the *CS2* tests detect contagion in all window lengths consistently in the whole period. The peak contagion statistics are in January 2010 in all coskewness tests for both Portugal and Spain. There is some isolated contagion from Greece in April 2010, but only in the 8-month window tests.

< Place Figures 19 and 20 About Here. >

As shown in figures 19 and 20 the results form the equity market tests are very similar to those of the bank sector indexes. The contagion to the Brazilian equity market is also strongest in early 2010, mostly originating in Portugal or Spain. There is very limited contagion from Greece in the *CS1* tests with 8-month windows. The main difference is that for the equity market indexes the contagion statistics have their highest values in February while in the bank sector indexes it was in January.

< Place Figure 21 About Here. >

There is also some correlation contagion detected in the CDS spreads, concentrated around April 2010, originating from Italy and Greece. The contagion from Greece is strongest both in terms of the value of the *FR* statistic and also in that it is present in the tests of all window lengths. The contagion from Italy is detected only in the 6 and 8-month tests. The results for the contagion tests in CDS spreads are shown in figure 21.

The end of 2009 and the beginning of 2010 see an increasing instability in the European economy due to the budget deficit problems faced by Greece. In December 2009, the Greek government announces €300 billion, about 113% of its GDP, almost the double of the Eurozone limit of 60%, and in the same month Standard & Poors downgrades the Greek sovereign debt from A- to BBB. This is a first indication of a financial crisis in the making in Greek economy.

In February 11 2010, the European Union (E.U.) leaders held the first emergency summit on Greece. The bank sector and equity indexes for Portugal and Spain are also affected as the fiscal challenges faced by those countries comes to light, and in April the ratings agencies downgrade the Portuguese and Spanish sovereign debts. This fiscal crisis in Europe can be the explanation for the contagion caused by Spain and Portugal in Brazilian economy, specially since large Spanish banks and firms operate in Brazil.

In April 8^{th} the Greek ten-year bond yield reaches 7.4%, and the spread on German bonds reaches a Euro-era high of 442 basis points. A spike in the CDS spreads happens in April which probably explains the CDS contagion to Brazil. In April 12 the E.U. finance ministers agree to provide €30 billion in loans to Greece in coordination with the International Monetary Fund (IMF) which is to make available another €15 billion in funds in the next year, after which very little contagion is detected until 2011.

The second period of contagion is in mid to late 2011 when contagion to Brazil is detected in both the bank and equity indexes with the *CS1* and *CS2* tests. In comparing the 4, 6 and 8-month window tests a pattern appears in that the window start dates (the dates that indicate a structural break in the statistic) are about two-months apart for each tests. That pattern implies that the actual contagion is stronger at the end of the windows being analysed, in September and October 2011. Also the tests indicate contagion from both Italy and Greece in the second period, in addition to Portugal and Spain.

The period from late 2010 through 2011 is marked by high volatility and generally unstable environment, specially towards the end of the sample period. In November 2010 Ireland requests further funds from the European Union. In March 2011 the Portuguese Prime Minister resigns, and in April Portugal also applies for further financial support from the European Union. CDS spreads for Greece soars to 45 times their December 2008 levels, and the spreads for Portugal, Spain, Ireland and Italy also rise sharply in 2011. All this contributed to general financial instability which influences the contagion to Brazil in 2011.

7. Concluding remarks

In this paper we have developed an approach for the timing of the contagion in a financial crisis through endogenous testing. We have shown that in the case of the Global Financial Crisis and the European Sovereign Debt Crisis the timing thus obtained is consistent with the important events and the general consensus of the crisis dating.

Our results show that contagion has been pervasive in the Global Financial Crisis and also in the European Sovereign Debt Crisis. The approach developed in this paper allows identifying contagion for a wide range of markets and countries and could be helpful for the design of specific stabilization policies. It is our understanding that these tests might be an additional tool for regulators and policy makers to assess the effectiveness of their policies and the communication of their actions.

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Table 1: Summary of the contributions

Authors	Period	Contagion	Market	Method	Contagion evidence
Baele and Inghelbrecht [5]	1973-2007	14 European countries	Equity markets	Dynamic factor model	Mixed findings
Longstaff et al. [35]	2006-2008	CDOs - other markets in US	CDOs market	Correlation test	YES
Manconi et al. [36]	2004-2007	Securitized bond market - corporate bond market in US	Bond Market	Correlation test	YES
Martinez-Jaramillo et al. [40]	2007-2009	Mexico	Interbank market	Systemic Risk Network Model (SyRNet)	YES
Ahlgren and Antell [1]	1980-2006	Effects between Germany, Japan, UK and US and between Hong Kong, Korea, Mexico and US	Stock market	Correlation break	NO
Rijckeghem and Weder [46]	1994, 1996 and 1997	Mexican, Thai, and Russian currency crises - 18 industrialized countries	Bank lending market	Correlation test	YES
Corsetti et al. [17]	October 1997	Stock market returns in Hong Kong - 10 emerging economies as well as the G7 countries	Stock market	Correlation break	YES
Rodriguez [47]	1993-1998	Asian crisis and Mexican crisis	Stock market	Copula	YES
Candelon et al. [13]	1994 and 1997	Mexican crises in Argentina, Venezuela, Colombia, Chile and Hong Kong crisis in Indonesia, Korea, Malaysia, Singapore, Taiwan and Thailand	Stock market	Common cyclical features	NO
Aloui et al. [2]	2004-2009	US - Brazil, Russia, India, China (BRIC)	Stock market	Copula	NO
Baur and Lucey [8]	1994-2006	Thailand (July 1997), Hong Kong (October 1997) and Russia (August 1998) - eight developed countries	Stock and bond market	Test for flight-to quality, flight-from-quality and cross-asset contagion	YES
Mendoza and Quadrini [41]	1982-2008	Effects of shocks to bank equities on asset prices	Net credit market	Model's quantitative predictions	YES
Dungey et al. [21]	1998	Russian bond default and the LTCM recapitalization announcement - 12 countries	Bond market	Latent factor model	YES
Baur and Schulze [6]	1997-2001	Asia - Latin America and Europe	Stock market	Quantile regression	YES
Fong et al. [25]	1987-2008	Between financial assets (US stocks and Treasury bonds), commodities (oil and gold) and real estate assets (US Case-Shiller index)	Stock market	General Markov switching model	Mixed findings
Markose et al. [39]	2008	US banks	CDS market	Systemic Risk Ratio, Complex Adaptive System (CAS), Agent-based Computational Economics (ACE) and SCAP Stress Test	YES
Andenmatten and Brill [3]	2008-2010	Greek debt crisis - 39 countries	CDS market	Approach proposed by Forbes and Rigobon [27]	YES
Baele and Inghelbrecht [5]	1973-2007	The Mexican crisis, the Asian crisis, the Russian/LTCM crisis, the Nasdaq Rash, 09/11 terrorist attacks, the Global Financial Crisis and periods of high market volatility	Stock market	The test developed by Bekaert et al. [10] (BHN test)	Mixed findings

Table 2: Summary of the contributions

Authors	Period	Contagion	Market	Method	Evidence of Contagion
Coudert and Gex [18]	2004-2007	General Motors (GM) and Ford crisis in 2005 - US and European firms	CDS market	Dynamic measures of correlations(EWMA and DCC-GARCH)	YES
Rigobon [44]	1994-1998	The Asian, Mexican, Russian/LTCM crisis	Bond and stock markets	OLS, PCA and new procedure based in Rigobon [45]	Mixed findings
Dungey and Yalama [22]	2004-2009	US - European equity markets during the global financial crisis	Stock market	The FR test and Hong test	Mixed findings
Forbes and Rigobon [27]	1987-1996	The Asian, Mexican and 1987 U.S. market crash	Stock market	Heteroskedasticity biases tests for contagion based on correlation coefficients	Mixed findings
Fry et al. [28]	1997-1998 and 2007	Hong Kong crisis and the Global Financial Crisis	Real estate and equity markets	Coskewness and Lagrange multiplier tests	YES
González-Hermosillos et al. [29]	1997-1998	Asian crisis	Equity market	Model of interdependence, Bivariate and Multivariate testing, AR and heteroskedastic dynamics, Forbes and Rigobon [27]contagion test, the BKS test and the DFGM test	Mixed findings
Forbes and Rigobon [26]	1982-2000	Mexican Debt Crisis, Asian Flu, the Russian Crisis, the Brazilian Crisis, Dot-com crisis - Latin America	Bond and stock markets	GARCH model and Heteroskedasticity biases tests	NO
Bodart and Candelon [12]	1994 and 1997	Mexican crisis - 4 Latin America countries and Asian crisis - 7 Asian countries	Equity market	Frequency domain approach	YES
Cipollini and Kapetanios [16]	1997-1998	East Asian countries	Stock market	Dynamic Factor model	YES
Khan and *Ken* Park [33]	1994-1999	Asian crisis - Thailand, Malaysia, Indonesia, Korea and Philippines	Stock market	Kalman filter	YES
Mistrulli [43]	1989-2008	Italy	Interbank market	Maximum entropy method	YES
Chiang et al. [15]	1990-2003	Asian crisis - 9 Asian market and US	Stock market	Dynamic conditional-correlation model	YES
Serwa and Bohl [48]	1997-2002	6 Crisis markets - Western European markets, and emerging markets in Central and Eastern Europe	Stock market	Heteroscedasticity-adjusted correlation	YES
Baur [7]	1979-2009	Financial sector - real economy of ten sectors in 25 developed and emerging countries	Stock market	Test four alternative types of contagion	YES
Mink and de Haan [42]	2010 (all year)	Greece - 48 European banks (that comprehend 17 European countries)	Stock market	The method examine excess returns in response to particular events, which are news about Greece and about Greek bailout	Mixed findings
Asgharian and Nossman [4]	1982-2007	US - 11 European coutries	Equity market	A stochastic volatility model with correlated jumps and a spillover model	YES
Grammatikos and Vermeulen [30]	2003-2010	Global Financial Crisis and European Sovereign Debt Crisis - 15 EMU countries	Stock market	Their is based on GARCH and factor models	YES

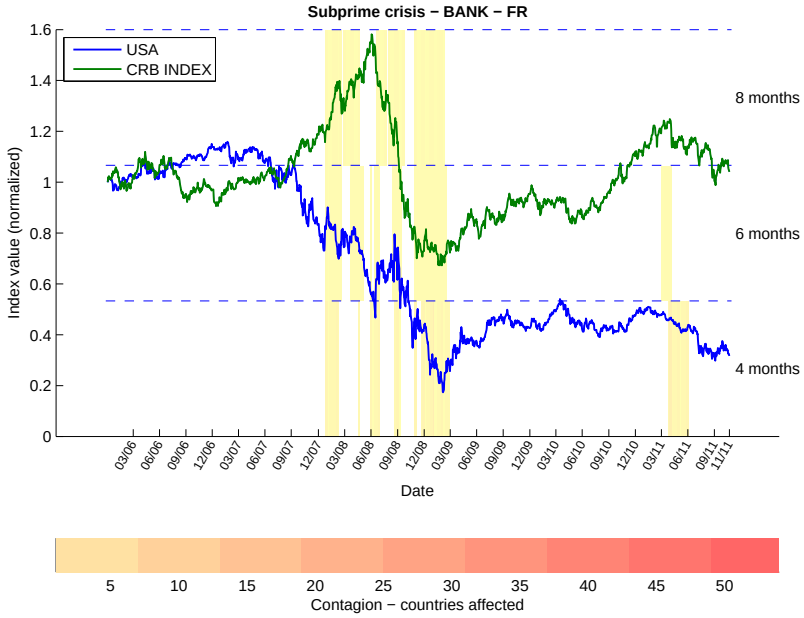

Figure 1: Global Financial Crisis contagion - Bank sector - FR

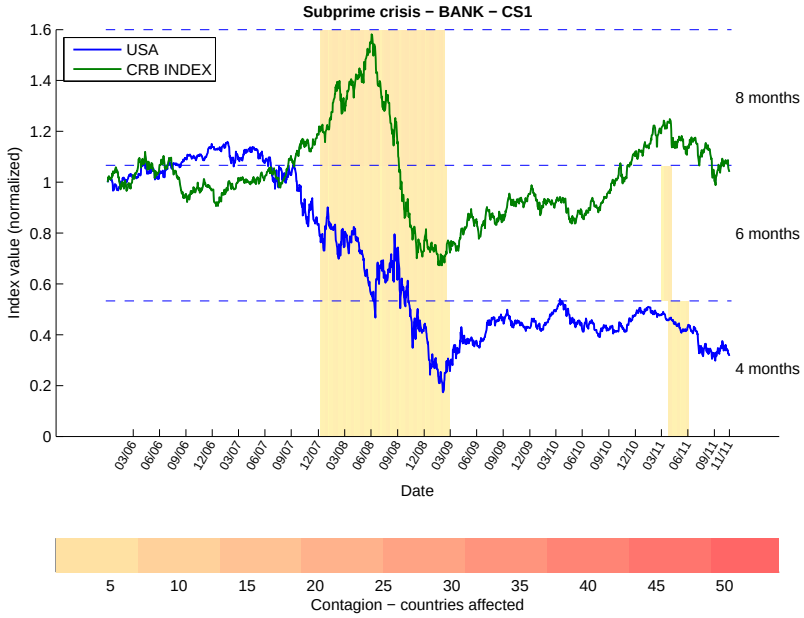

Figure 2: Global Financial Crisis contagion - Bank sector - CS1

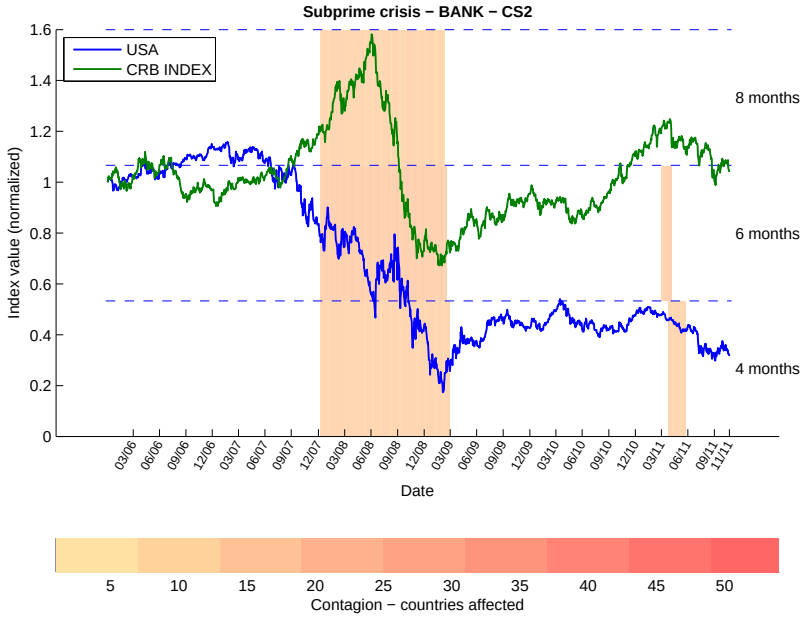

Figure 3: Global Financial Crisis contagion - Bank sector - CS2

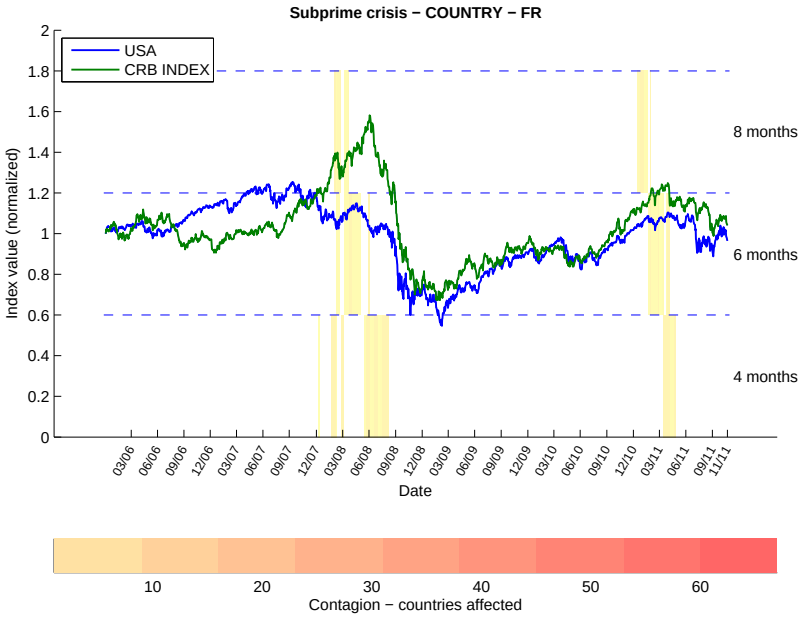

Figure 4: Global Financial Crisis contagion - Equity - FR

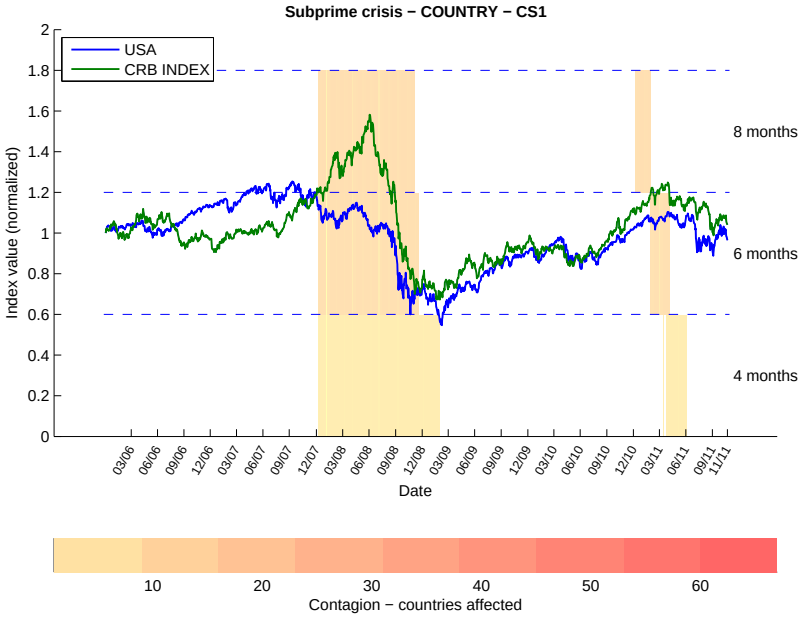

Figure 5: Global Financial Crisis contagion - Equity - CS1

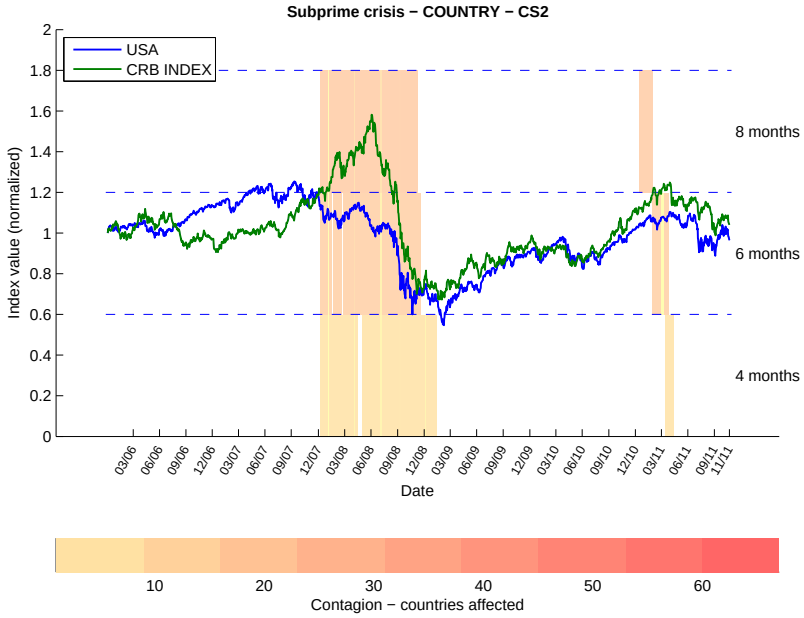

Figure 6: Global Financial Crisis contagion - Equity - CS2

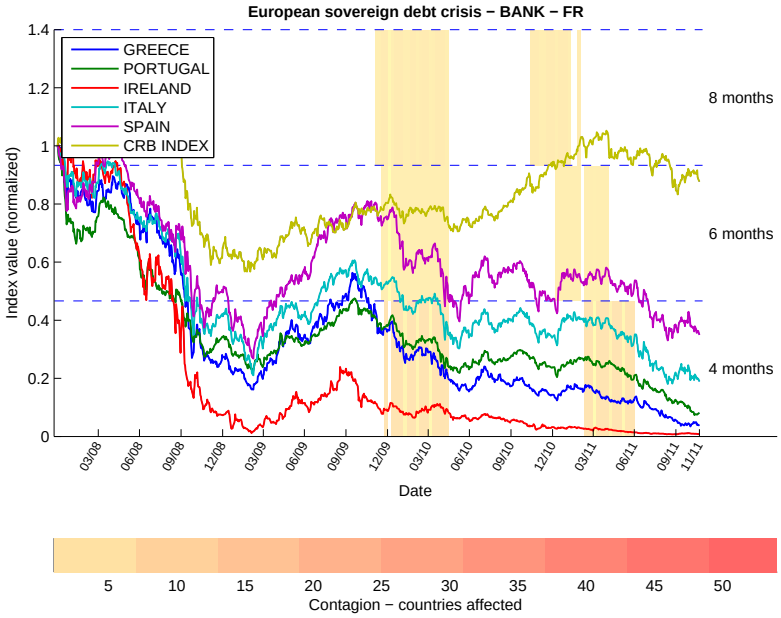

Figure 7: European Sovereign Debt Crisis contagion - Bank sector - FR

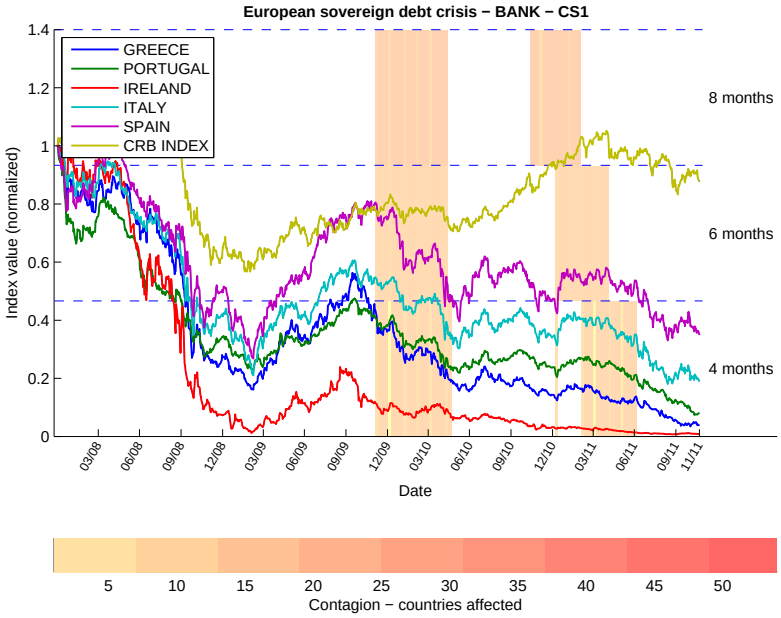

Figure 8: European Sovereign Debt Crisis contagion - Bank sector - CS1

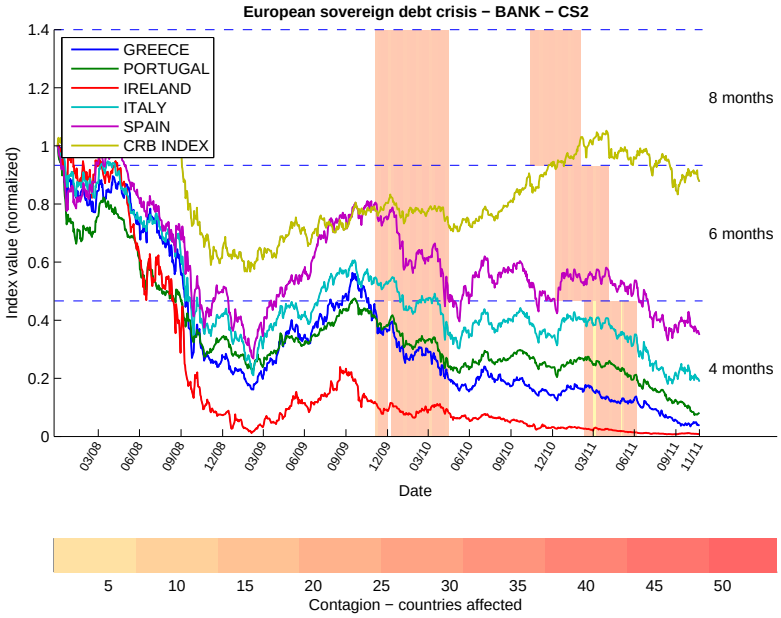

Figure 9: European Sovereign Debt Crisis contagion - Bank sector - CS2

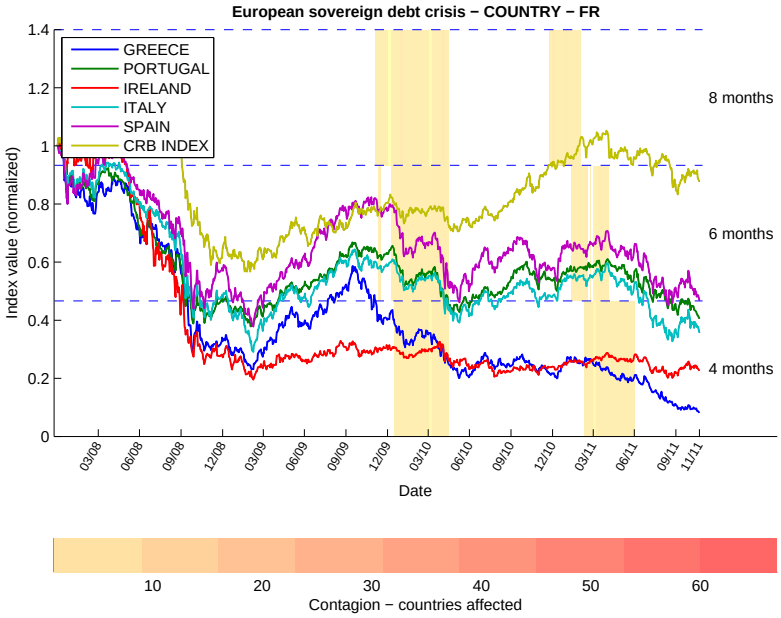

Figure 10: European Sovereign Debt Crisis contagion - Equity - FR

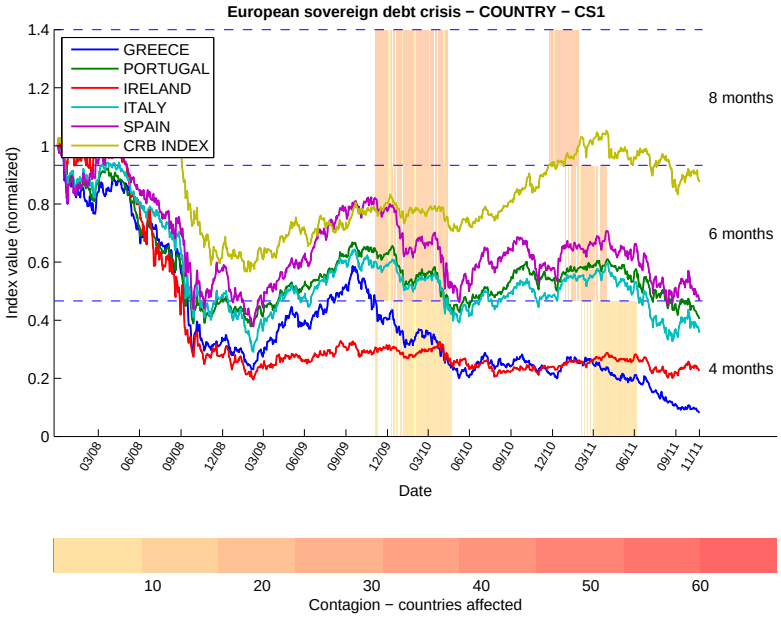

Figure 11: European Sovereign Debt Crisis contagion - Equity - CS1

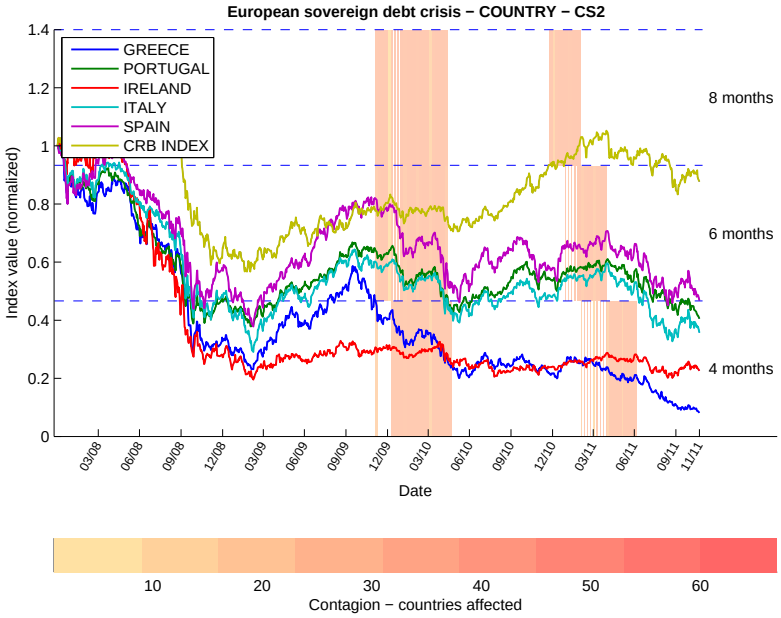

Figure 12: European Sovereign Debt Crisis contagion - Equity - CS2

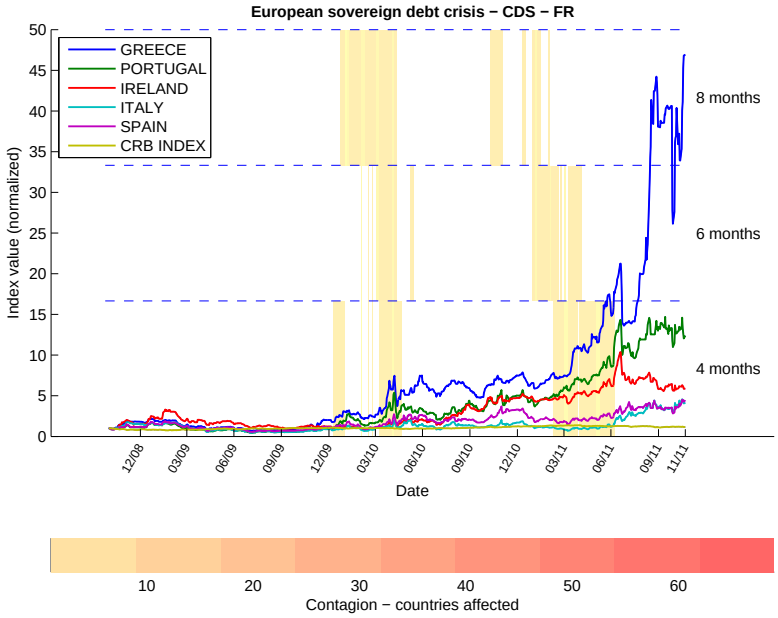

Figure 13: European Sovereign Debt Crisis contagion - CDS - FR

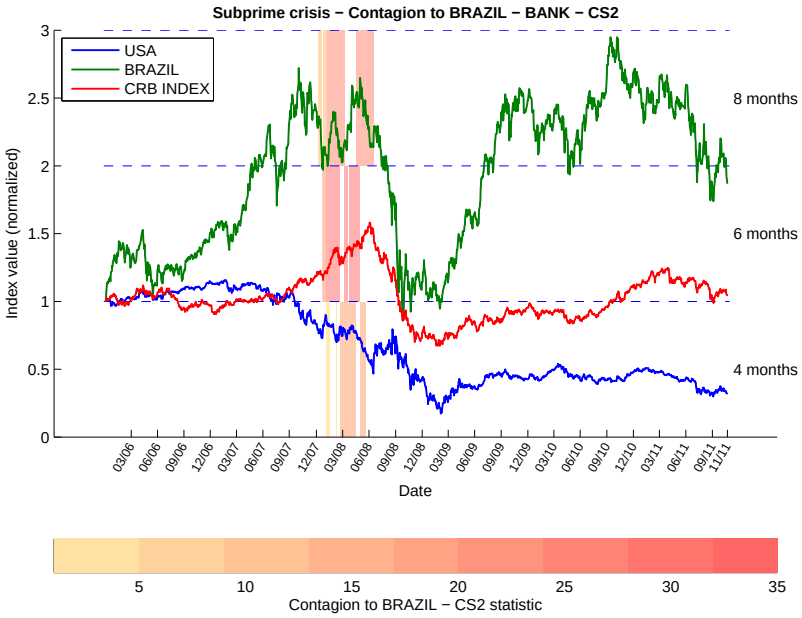

Figure 14: Global Financial Crisis contagion to Brazil - Bank sector - CS2

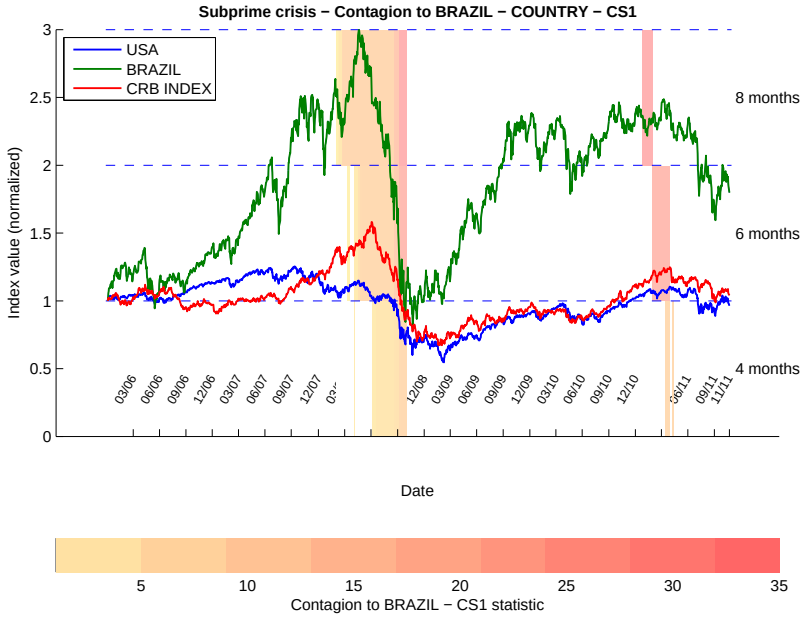

Figure 15: Global Financial Crisis contagion to Brazil - Equity market - CS1

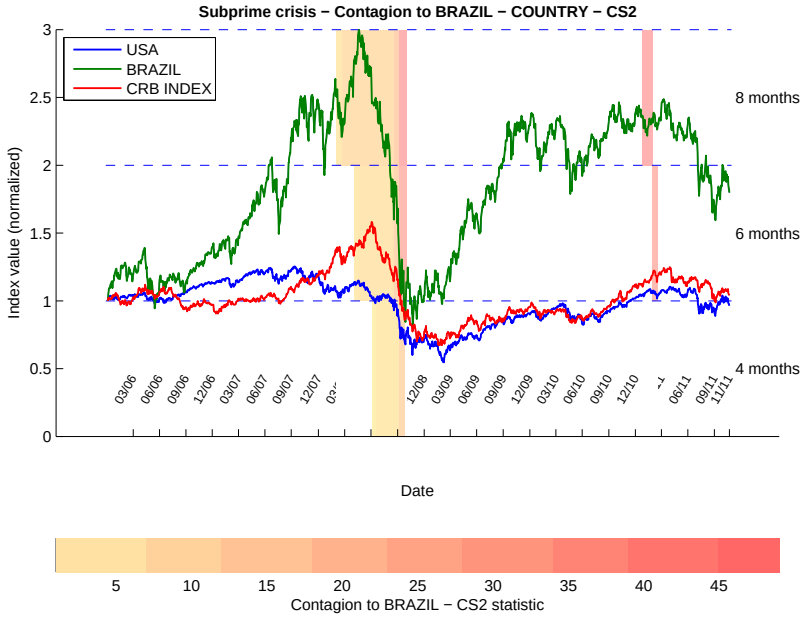

Figure 16: Global Financial Crisis contagion to Brazil - Equity market - CS2

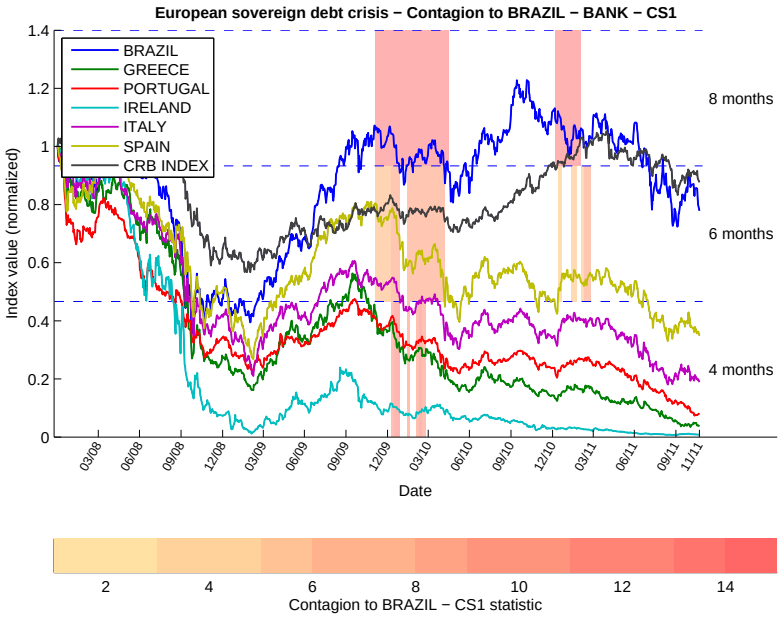

Figure 17: European Sovereign Debt Crisis contagion to Brazil - Bank sector - CS1

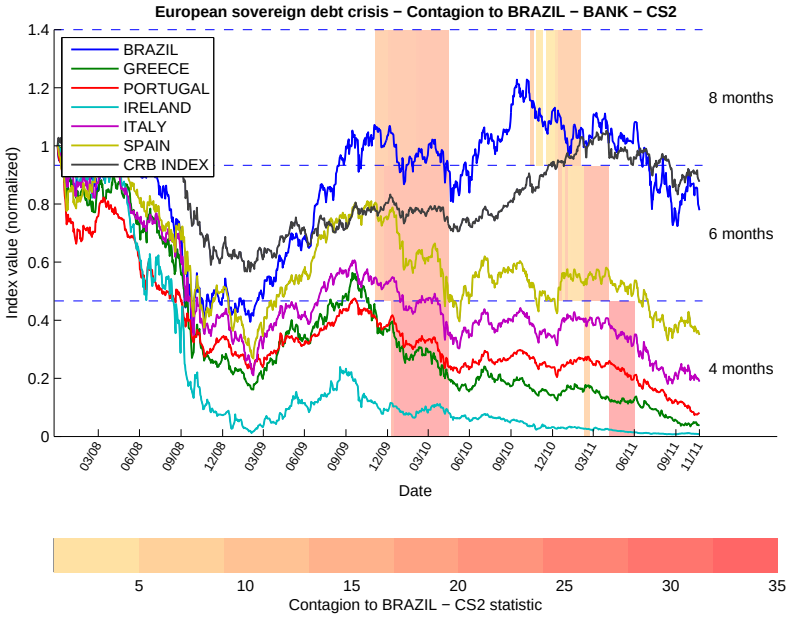

Figure 18: European Sovereign Debt Crisis contagion to Brazil - Bank sector - CS2

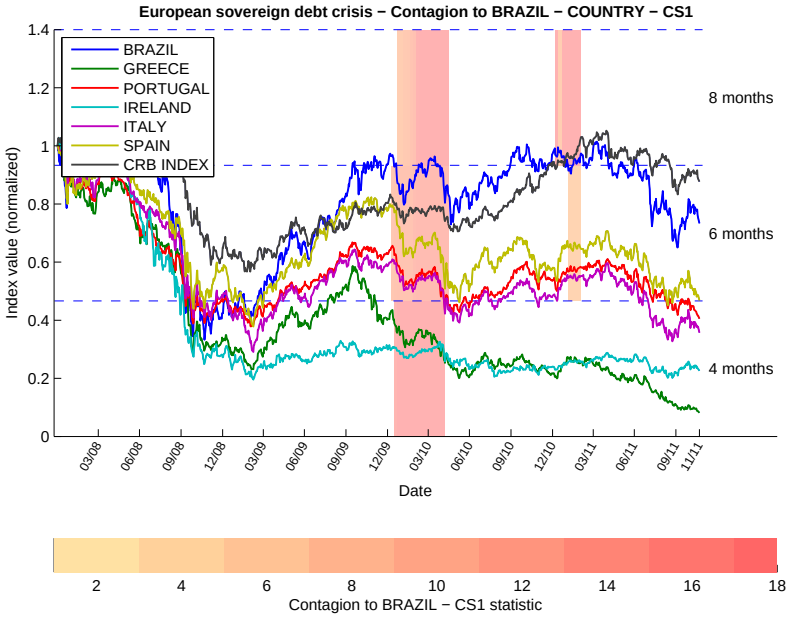

Figure 19: European Sovereign Debt Crisis contagion to Brazil - Equity - CS1

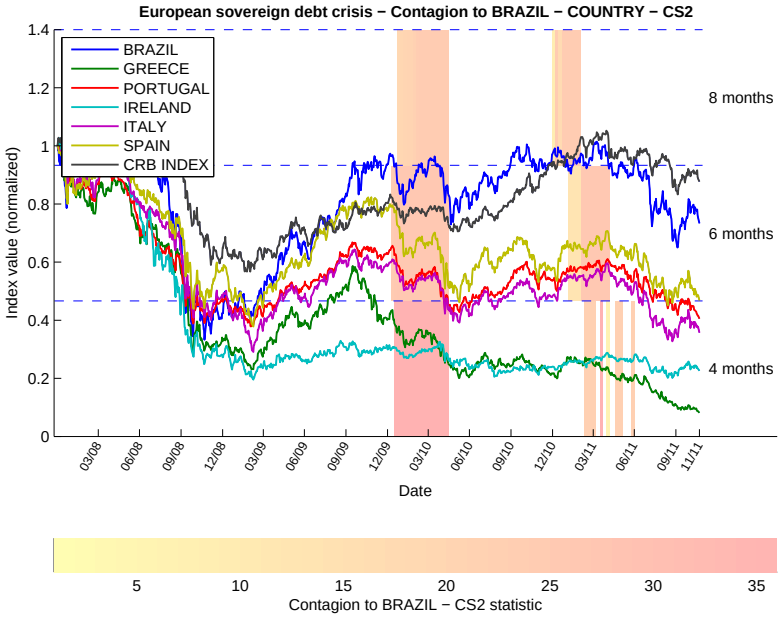

Figure 20: European Sovereign Debt Crisis contagion to Brazil - Equity - CS2

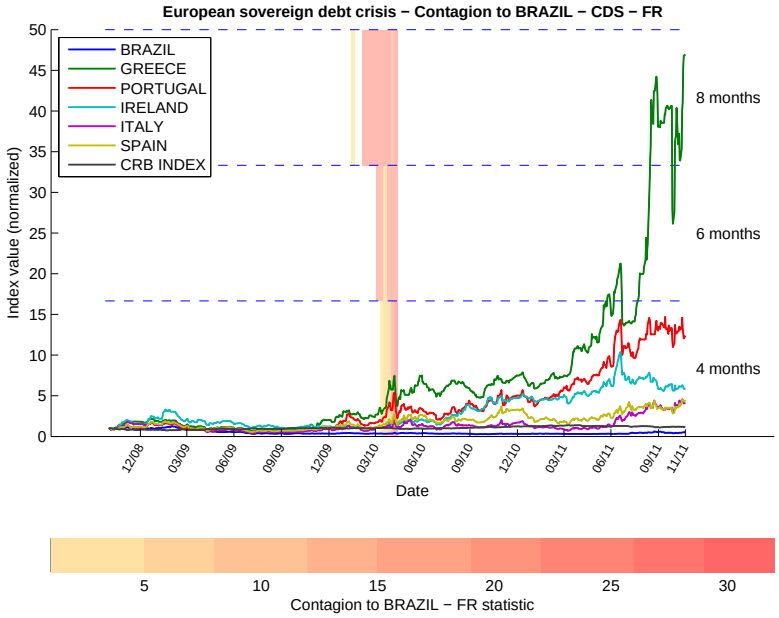

Figure 21: European Sovereign Debt Crisis contagion to Brazil - CDS - FR