Contagion in public debt markets: A cointegration approach with nonstationary volatility*

Josep Lluís Carrion-i-Silvestre† Óscar Villar‡

March 9, 2015

Abstract

In this paper, we investigate whether financial contagion happened in sovereign bond markets of selected OECD industrialized countries during the last great recession. We analyze whether the co-movement of their debt markets was based on normal interdependence or, on the contrary, they suffered contagion, a situation that is found when there are instabilities affecting the global and local transmission mechanism of financial stocks. We use cointegration models to capture the financial markets co-movement by examining which markets were the most internationally synchronized. We distinguish between the global contagion –multivariate cointegration linked to *non-diversifiable risk* as global liquidity conditions and agent's risk aversion– and pure contagion– bivariate cointegration linked to the improvement of the local or regional economic fundamentals of a given country. Also, we distinguish others for two forms of contagion, the long term contagion and short term contagion. Our sample covers 22 developed countries using daily data of bond markets during the period 1999-2014. We find evidence of significant instabilities in cross-market linkages during the crisis.

Keywords: Contagion, financial crisis, Granger causality, cointegration, debt market

JEL classification: C12, C22

---

*The authors gratefully acknowledge the financial support from the CICYT project ECO2011-30260-C03-03.

†AQR-IREA Research group. Department of Econometrics, Statistics and Spanish Economy. University of Barcelona. Av. Diagonal, 690. 08034, Barcelona. E-mail: carrion@ub.edu

‡AQR-IREA Research group. Department of Econometrics, Statistics and Spanish Economy. University of Barcelona. Av. Diagonal, 690. 08034, Barcelona. E-mail: ovillar@ub.edu

1 Introduction

The financial crisis that was originated in the US in 2007 developed into a global financial turmoil and a long lasting recession in many economies of the globe. The origin of the crisis can be traced back to the increase of unpaid mortgage loans, mostly extended to less creditworthy borrowers (sub-prime loans), that affected the stability of financial institutions exposed to them as well as to the tenants of financial products tied to these mortgages.[1] This all resulted in the collapse of large financial institutions, the bailout of affected banks and downturns in stock markets, which, in turn, required political intervention.

The crisis affected other countries due to standard practices of the financial institutions such as securitization and off balance sheet financing. By the end of 2007, equity markets started falling from their peaks as a consequence of the sub-prime problem in the US and western countries such as Spain, UK, Ireland or Greece, who suffered fast and sudden downturns in their financial markets. In this context, many states all over the world, especially in Europe, saved their institutions by absorbing most of the financial industry risk. Thus, the risk of the industry was passed to excessive sovereign debt. Therefore, the global financial crisis has evolved into a sovereign debt crisis. Some of them even required assistance from international institutions such as the International Monetary Fund (IMF) or the European Central Bank (ECB) who implemented measures to reestablish financial stability and the confidence in their banking and financial systems.

During the Global Financial Crisis (GFC) and European debt crisis, it can be observed a large increase in the correlation between the stock returns of the largest OECD countries. Intuitively, this can be understood as evidence of contagion or financial shock spillover among financial markets across different regions. It is important to differentiate between cross-country linkages that exist at all times –what is often called interdependence– versus linkages that only exist briefly after shocks –what is called contagion. Specifically, we define interdependence when we confirm that there exist similar cointegration relationships among bonds between pre-crisis and crisis periods. If we do not find a similar relationships of cointegration, we could consider that contagion exists. Contagion modifies the long-run links among financial markets, but not the interdependence that links these markets. Monitoring the stability of cointegration relationship is important in international investment for international portfolio management and risk assessment. Contagion might lead to that risk cannot be mitigated by a smaller opportunity of diversification in international investment for international portfolio management. In European bond markets context, the bond contagion is important for the transmission of the European Central Bank policy among European countries. The greater integration or contagion of European bond markets may reduce the efficiency of the common monetary policy to maintain price stability among long-term interest rates.[2] Therefore, it is important differentiating between contagion and interdependence because policies which impose additional adjustment on a country can create additional risks by increasing their vulnerability to contagion. Furthermore, the cross-border contagion may have significant consequences for finan-

---

[1] See Markose, Giansante, Gatkowski, and Shaghaghi (2009) for the analysis of too big to fail and the system risk.

[2] See Clare, Maras, and Thomas (1995).

cial stability. The cross-border shocks in one country are transmitted to other countries and this interdependence or contagion may have adverse consequences for the stability. This instability has led us to analyze the main causes of co-variation of the stock markets in the most industrialized countries during the financial crisis.

The definition of contagion versus interdependence is useful in order to understand the policy implications and its evaluating policy responses. The more restrictive definition allows us better understand how crises are transmitted and what should be done. If the transmission of crises is among interdependence, i.e., the cross-country linkages are the same in all states of the world, policies that provide liquidity or financial assistance will be less effective in reducing contagion. In this case these policies just delay a necessary adjustment. But if there is contagion, i.e. that cross-country linkages only exist briefly after shocks –such as panic or a temporary liquidity risk– then policies to provide liquidity or financial assistance until economic relationships stabilize could potentially avoid an unnecessary and painful adjustment.[3]

Nevertheless, it is necessary to understand that the globalization and the different processes of financial integration/convergence have created a clear interrelationship among the markets. For this reason, we consider it necessary also to analyze the literature of markets integration and its results. In particular, any analysis that pursues to investigate the presence of contagion has to take into account this integration or interdependence relationship to guarantee that the conclusions of the study are not misleading. The existence of cointegration, that implies markets integration, would contradict this financial theory about Efficient Market Hypothesis because the returns of one market can be predictable in the long run from the returns of the other. Granger (1986) concludes that silver and gold prices are not cointegrated once these markets are weak efficient market.[4] Related to this markets integration literature, another way of understanding the contagion could be as change of cointegration (convergence or divergence) only in times of crisis.

In the present paper we analyze the presence of contagion in the financial crisis taking into account the strong dependence that exists among the economies. The main contributions of the article are the following ones. First, we analyze the current crisis using up to date data, which allows us to give possible solutions to the present situation. Second, we carry out the study using flexible and robust unit root test. We only find Carrion-i-Silvestre and Villar (2014) in the contagion literature that has used these tests. We choose this test because it captures all the properties of the financial time series.[5] Third, we also analyze the presence of cointegration using a new procedure that is robust to main econometrics problems of the financial time series in contagion. We did not find any paper in the contagion literature that has used this cointegration test. Fourth, we do not need to determine endogenously or exogenously the different regimens of volatility (non-stationary volatility) so that the cointegration test assume that the univariate process can have these characteristics. Fifth, cointegration controls for the strong dependence that exists among the

---

[3] See Forbes (2012) for more details.

[4] Other authors pointed out that cointegration and efficiency would not be incompatible. See, for example, Dwyer and Wallace (1992) or Darrat and Zhong (2002).

[5] See Forbes and Rigobon (2002) for the econometrics problems about contagion testing.

financial variables. Further, cointegration allows us take into account any channel of transmission that is acting to spread the crisis among different countries. The transmission mechanism can take many forms and most of them result from a healthy interdependence between countries in good times, as well as in bad times.[6] This technique also identifies and quantifies the effects of the crisis transmission without resorting to ad hoc identification of the fundamentals. Besides, this procedure allows us to draw conclusions that are robust to the omission of relevant variables and simultaneous equations bias problems.[7] From a policy point of view, it is essential to provide policy makers with timely and appropriate measures of correlation changes and contagion. This will certainly help to design appropriate policy responses and prepare contingency plans. Lastly, the GFC has expanded the definition of contagion. The fact that the GFC originated in the US has led us to consider a global shock or a shock to a large economy that is transmitted to others as a type of contagion. Thus, one now needs to distinguish among two types of contagion: "local contagion" and "global contagion". The local contagion might be bilateral linkages between countries. The global contagion is the multilateral relationship among countries. It is the relationship of a country with the systemic risk or global economy. This definition of contagion allows us to analyze in more detail the possible causes and consequences of the transmission of the shock. These two types of contagion are useful in terms of policy implications. Each contagion has different policy implications. The global contagion has a consequence in the global regulation and local contagion has implications in regional or local regulation. The latter concept that is introduced in this paper is the distinction between strong and fast contagion. We consider the dependence or cointegration of the variables in levels among the markets is a long run dependence, that is persistent in the long term and, therefore, stronger. Instead short-run dependence that can be found among the first difference of the variables, that it is one more ephemeral and fast dependency. These two types of dependence also are useful in terms of policy implications.

This article proceeds as follows. Section 2 briefly discusses the main contagion empirical literature. Section 3 discusses data that is used in this paper. Section 4 analyzes the empirical results focusing on, first, the order of integration of the time series and, second, on the analysis of parameter stability of the cointegration and Granger causality. Finally, Section 5 presents some concluding remarks.

2 Contagion literature: An overview

In this section, we give a short overview of the empirical approximations that have been followed in the literature to analyze the presence of contagion in periods of crisis. Although the focus of this section is based on the empirical approaches, it is worth introducing a brief comment on the theoretical contributions that have tackled the issue of financial crises and contagion. An extensive

---

[6] In addition to this important feature for the contrast of "shift contagion". We see that the cointegration is also been used for the analysis channel of transmission. See Giordano, Pericoli, and Tommasino (2013), De Santis (2012) or Gómez-Puig and Sosvilla Rivero (2014).

[7] See Forbes and Rigobon (2002) for the econometrics problems about contagion testing.

literature exists in the strictly theoretical field, which has given rise to diverse models or generations of models that explain the transmission of financial crises among countries and financial markets.[8]

Due to the evolution of theoretical models, it is possible to find different definitions of contagion.[9] Basically, there are two ways to define financial contagion. The first approach defines contagion depending on the channels of transmission that are used to spread the effects of the crisis. The second concept defines "shift-contagion" or contagion depending on whether the transmission mechanisms are stable through time.[10] In the last definition, if the transmission among markets has been stable in different moments of time, we could conclude that there is a relation of interdependence among markets, whereas if this transmission changes through time, then, we will be facing a situation of contagion or "shift-contagion".[11]

The definition that we rely on throughout this paper is the one that allows us to confirm the existence of contagion with regard to the situation of interdependence. This definition of contagion conveys the break or breaks in the transmission mechanism for the crisis owing to financial panics, herding or switching expectations across instantaneous equilibria.[12] Specifically, we wish to focus on two types of contagion:[13] global contagion or systemic risk, and local or pure contagion. At a theoretical level we note two theories to support our definition. Masson (1998) found these two types of contagion or interdependence. First, the theory of "monsoonal effects" and, second, the theory of "spill-over effect". The first one implies that contagion during crises hits hardest those economies that are highly globally integrated, such as through trade and financial linkages.[14] The second one is "pure contagion", which implies that there is a significant increase or "shift" in cross-market linkages after a shock to an individual country.

Among the econometric approaches that enable us to analyze contagion, we have selected the methodology that is based on cointegration and Granger causality definitions. We have chosen these approaches for several reasons. First, we believe that is the best way to discern between a stable long-term relationship and a relationship that acts in short term. Cointegration really allows us to find whether this relationship exists in the long run. Second, these approaches not impose a unique channel of contagion on the model, but it allows us to fit the combinations of various mechanisms of transmission among countries. In addition, the use of a multivariate cointegration approach will allow us to eliminate problems associated with the omission of relevant variables and

---

[8] The development of the literature from the first through fourth-generation models, or the so-called "institutional" models, is reviewed by Breuer (2004). Other relevant surveys are Belke and Setzer (2004) and De Bandt and Hartmann (2000).

[9] See Pericoli and Sbracia (2003) for the different definitions of contagion.

[10] This definition of contagion is related to the approach of Boyer, Gibson, and Loretan (1997), Forbes and Rigobon (2001) and Forbes and Rigobon (2002).

[11] Overviews of the issues are provided by Dornbusch, Park, and Claessens (2000), Pericoli and Sbracia (2003), Belke and Setzer (2004) and De Bandt and Hartmann (2000), among others.

[12] The change of the channels and intensity of shocks propagation in crisis periods could be explained by the role of multiple equilibria.

[13] Bekaert, Harvey, and Ng (2005), Bekaert, Ehrmann, Fratzscher, and Mehl (2011) and Baur and Fry (2009) use these definitions.

[14] Bekaert, Harvey, and Ng (2005) use this definition. Others paper that studies "global shocks" are Calomiris, Love, and Peria (2010), Fratzscher (2012) and Eichengreen, Mody, Nedeljkovic, and Sarno (2012).

simultaneous equations estimation bias.[15]

At the empirical level, we consider that cointegration approach is the best specification that reflects and caught up our definitions of contagion. This econometric specification allows us to distinguish between a stable long-term (strong interdependence or strong contagion) and short-term (fast interdependence or fast contagion) in the financial contagion. The cointegration approach also allows us to identify the main causes or channels of global and local contagion.[16]

We can broadly divide the literature into two major strands. The first one, the markets integration or markets convergence, computes the number of common stochastic trends using cointegration mainly focusing on time-varying cointegration relationships (recursive and rolling cointegration). One of the first approximations that used cointegration in this framework was Kasa (1992).[17] After this seminal work, a notable volume of literature has analyzed the presence of contagion using time-varying cointegration.[18] At this point, we wish to emphasize the abundant cointegration literature that analyzes the convergence or markets integration but without taking into account the periods of crisis or/and unconditional volatility. The crises entail a change in the unconditional volatility and classical cointegration analysis are not robust to non unconditional volatility. Some papers taken into account the structural break in the mean but we have found none who has had the account the structural break in variance to the cointegration analysis. We contribute with a new cointegration tests robust to the unconditional volatility to analyze markets integration and strong contagion.

The second strand is financial contagion literature.[19] One of the first approximations that used cointegration in this framework was Cashin and McDermott (1995).[20] After this seminal work, a notable volume of literature has analyzed the presence of contagion using cointegration and Granger causality on different markets and financial crises, but mainly focusing in Granger causality.[21] In this article we relate the fast contagion with the literature of Granger causality. Our approach is then more related to the works of Yunus (2013), Fofana and Seyte (2012) and Gentile and Giordano (2012), who use a cointegration test to analyze the “shift contagion”.[22]

3 Data and sample

The data source is Thomson Reuters Financial Datastream, from which we have selected a sample including 22 (OECD industrialized) economies: Australia, Austria, Belgium, Canada, Denmark,

---

[15] See Forbes and Rigobon (2002) for the econometrics problems about contagion testing.

[16] See Bekaert, Ehrmann, Fratzscher, and Mehl (2011).

[17] Another papers in which cointegration is also analyzed are Corhay, Rad, and Urbain (1993) or Richards (1995).

[18] Another papers in which cointegration is also analyzed are Rangvid (2001), Pascual (2003), Voronkova (2004), or Basse (2014).

[19] For survey of cointegration in contagion see Mollah and Hartman (2012). In the introduction of AuYong, Gan, and Treepongkaruna (2004) can also see a brief summary of the contagion test using cointegration and Granger causality.

[20] Another papers in which cointegration is also analyzed are Longin and Solnik (1995) or Malliaris and Urrutia (1992)

[21] See Khalid and Kawai (2003), Sander and Kleimeier (2003), Gómez-Puig and Sosvilla-Rivero (2014) or Lee, Tucker, Wang, and Pao (2014).

[22] See also Corsetti, Pericoli, and Sbracia (2005), Forbes and Rigobon (2002), Dungey, Martin, and Pagan (2000) and Bekaert, Harvey, and Ng (2005).

Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States. The data employed that we use in this paper is the daily average redemption yield annualized in local currency of benchmark 10 year maturity government bond market indices (10-year sovereign bond yields). We select the long-term government bonds instead of shorter-term ones because the monetary policy operations are more likely to have an clearer influence on long-term government bonds than on short-term ones [23] and the long-term government bonds can be used as closer maturity substitutes to stocks.

We choose the Benchmark indices because they are based on single bonds. The bond selected for each economy is the most representative bond available for the given maturity band at each point in time. Benchmarks are selected according to the accepted conventions within each market. Generally, the benchmark bond is the latest issue within the given maturity band; consideration is also given to yield, liquidity, issue size and coupon. The constituents are reviewed at the beginning of each month, and any changes are made at that time. Constituents are then fixed until the start of the following month.[24]

The Average Redemption Yield - Annualized (RA) presents the return on a bond if it is bought today at the market price and is held to its maturity date. This yield does not only reflect the gain or loss held when it matures, but also the future and present interest payments. The redemption yield is the discount rate at which the sum of coupons and principal from the bond, all future cash flows, is equal to the price of the bond. The Average Redemption Yield - Annualized is calculated as:

$$RA_{i,t} = \frac{\sum_{j=1}^{n} Y_{i,j,t} * D_{i,j,t} * (P_{i,j,t} + A_{i,j,t}) * N_{i,j,t}}{\sum_{j=1}^{n} D_{i,j,t} * (P_{i,j,t} + A_{i,j,t}) * N_{i,j,t}}$$

where: $RA_{i,t}$ is a Average Redemption Yield - Annualized on day t for the i-th time series index, $Y_{i,j,t}$ is the redemption yield to assumed maturity on day t for the j-th bond in the i-th time series index, $D_{i,j,t}$ is the duration of the j-th bond in the i-th time series index on day t, $P_{i,j,t}$ is the clean price on day t for the j-th bond in the i-th time series index, $A_{i,j,t}$ is the Accrued interest to the "normal" settlement date for the j-th bond in the i-th time series index on day t, $N_{i,j,t}$ is the nominal value of amount outstanding is known, otherwise the issued amount, on day t for the j-th bond in the i-th time series index.[25]

The frequency of the data set is daily (Monday to Friday) and the period covers from April 1st, 1999 through November 17th, 2014. This period is selected so that it enables analysis the both tranquil and crisis periods and it avoid possible problems for the introduction of the Euro. We choose daily data because we thought that lower frequency series may lost part of the information on financial interdependence and contagion.

---

[23] See Urich and Wachtel (2001).

[24] See Datastream Government Bond Indices.

[25] See Datastream Global Equity indices User Guide.

4 Empirical Analysis

4.1 Univariate analysis

In this section we will analyze each 10-year sovereign bond yields. The sovereign bond series, as other financial time series, are expected to show conditional and unconditional volatility in their variance. In the period of time that we are analyzing, we expect that some bonds are affected by the presence of structural breaks in variance (unconditional heteroskedasticity),[26] which can be due, for instance, to different intensities of each financial markets in crisis periods. We address the issue of the non-stationary volatility (unconditional heteroskedasticity), one of the most common econometric problems in the analysis of "shift-contagion". First, the non-stationary volatility in the univariate level can involve a change in the unconditional variance-covariance matrix at a multivariate level, which in turn can mislead the interpretation of financial contagion.

In econometric terms, a structural change in volatility invalidates the classical unit root test and cointegration test. The stationary time-varying conditional variance (conditional heteroskedasticity) does not influence in the unit root test and cointegration test[27] but non-stationary volatility can have a strong influence in the limiting distribution of these tests under the null hypothesis.[28]

In this section, we proceed testing for the existence of unconditional heteroskedasticity (Sansó, Aragó, and Carrion-i-Silvestre (2004)), showing that this feature is present in our dataset.[29] Then, we compute unit root tests that must be robust to unconditional heteroskedasticity. To the best of our knowledge, there is only other contribution, Carrion-i-Silvestre and Villar (2014), in the empirical literature that analyzes financial contagion. However, non-stationary volatility has a great influence on the stochastic properties of the processes and the unit root test. In order to overcome this drawback, in this paper, we consider a bootstrap-based statistic proposed by Smeekes and Taylor (2012) that is robust to non-stationary volatility,[30] trend uncertainty[31] and uncertainty about the initial condition.

The Smeekes and Taylor (2012) test specifies the null hypothesis of unit root ($H_0 : c = 0$) against the alternative hypothesis of I(0) ($H_0 : c > 0$) based on the specification of the following data-

---

[26] See Forbes and Rigobon (2002) for the non-stationary volatility problems about contagion testing.

[27] See Hansen and Rahbek (1998), Cavaliere (2003) or Ling, Li, and McAleer (2003).

[28] See Hamori and Tokihisa (1997), Kim, Leybourne, and Newbold (2002) or Cavaliere and Taylor (2008).

[29] See Wang and Nguyen Thi (2013) and Dungey and Gajurel (2014) for the study of endogenous break of the unconditional heteroskedasticity in financial contagion.

[30] Cavaliere and Taylor (2008) includes in non-stationary: both single and multiple abrupt breaks in variance, polynomially trending volatility, piecewise trending volatility, and smooth transition variance breaks.

[31] Robust to with and without a deterministic linear trend.

generating process (DGP). In order to simplify the exposition we the i subscript from the notation:

$$\begin{aligned} y_t &= x_t + \mu + \beta_T t \\ x_t &= \rho_T x_{t-1} + u_t \\ u_t &= \sum_{j=0}^{\infty} \psi_j \epsilon_{t-j} =: \psi(L)\epsilon_t, \qquad (\psi_0 = 1) \\ where &: \rho_T = 1 - \frac{c}{T} \end{aligned}$$

$t = 0, 1, \ldots, T$.[32] The Smeekes and Taylor (2012) union test statistic is:

$$\begin{aligned} UR^*_{4,\widetilde{\gamma}}(\pi) &= \min(DF - QD^{\mu^*}_{\widetilde{\gamma}}, (\frac{c\nu^{\mu^*}_{QD}(\pi)}{c\nu^{\tau^*}_{QD}(\pi)})DF - QD^{\tau^*}_{\widetilde{\gamma}}, \\ & (\frac{c\nu^{\mu^*}_{QD}(\pi)}{c\nu^{\mu^*}_{OLS}(\pi)})DF - OLS^{\mu^*}_{\widetilde{\gamma}}, (\frac{c\nu^{\mu^*}_{QD}(\pi)}{c\nu^{\tau^*}_{OLS}(\pi)})DF - OLS^{\tau^*}_{\widetilde{\gamma}}) \\ where\ DF &: (Augmented)\ Dickey - Fuller\ Test \end{aligned}$$

and the critical value is:

$$c\nu^*_{UR,\widetilde{\gamma}}(\pi) = \max\{x : N^{-1} \sum_{b=1}^{N} I(UR^*_{4,\widetilde{\gamma},b}(\pi) < x) \leq \pi).$$

The results of Smeekes and Taylor (2012) test statistic are presented in Table 1 for both the Bonds series and first difference of the Bonds series. As can be seen, the null hypothesis of unit root is clearly rejected at the 5% level of significance when applied on the first difference of the time series, whereas it is not rejected when computed on the time series in levels. Therefore, we conclude that the returns of Bonds are I(1) stochastic processes. Consequently, the overall conclusion in this section is that all time series are I(1) non-stationary stochastic processes.

Let us now focus on the analysis of the unconditional volatility of the different series. The unconditional volatility analysis allows us to confirm the importance of Smeekes and Taylor (2012) test in the study of financial contagion. The unconditional heteroskedasticity is a common feature in financial series,[33] a characteristic that needs to be considered when carrying out the order of integration and cointegration analyses.

The analysis of the unconditional volatility is relevant because this is one of the most important contributions of the Rigobon (2003) paper to the financial contagion literature. Further, we also find different characteristics in the descriptive analysis that makes us think of that this econometric problem exists in the data that is analyzed in this paper.[34] We want to test whether the unconditional variance experiences changes throughout the period analyzed, for each first difference of

---

[32] With the assumption 1' (Non-stationary volatility), 2 (Trend uncertainty), 3 (Uncertainty about the initial condition), 4 and 5 of the Smeekes and Taylor (2012).

[33] See, for example, Cavaliere and Taylor (2008).

[34] See Table 16

the bonds.[35] To analyze the structural change in the unconditional variance we choose the κ_2 statistic in Sansó, Aragó, and Carrion-i-Silvestre (2004).[36] The κ_2 statistic in Sansó, Aragó, and Carrion-i-Silvestre (2004) is not robust to conditional heteroskedasticity. So, first we need to test for the presence of a GARCH structure and estimate a GARCH for the whole period before we compute the κ_2 test Sansó, Aragó, and Carrion-i-Silvestre (2004).[37] We select the whole period because under the null hypothesis in Sansó, Aragó, and Carrion-i-Silvestre (2004) there is constant unconditional and conditional heteroskedasticity.[38]

We test and filter each first difference of the time series for conditional variances with the GARCH structure. This procedure can help us to test the unconditional variance. Before, we test the conditional mean because the misspecification of the conditional mean provokes poor properties of GARCH test.[39] The results of this test are showed in Table 3. After the conditional mean analysis, we compute the Engle (1982) and Broock, Scheinkman, Dechert, and LeBaron (1996) LM tests to study the volatility of first difference of the bonds. The computation of both tests statistics leads to the same conclusion, i.e., the first difference of bonds has a non-constant conditional volatility. These results are consistent with the correlograms of the series and their squares.[40] The results indicate that the GARCH specification is plausible. Finally, we analyze for nonlinear GARCH structure or leverage effect, using the Sign Bias (SB), Negative Size Bias (NSB), and Positive Size Bias (PSB) tests and the general test for asymmetric volatility effects.[41] The results of these statistics are reported in Table 6, which point to the presence of non-constant conditional volatility in our data.[42]

Finally, before we compute the κ_2 statistic in Sansó, Aragó, and Carrion-i-Silvestre (2004), we estimate the GARCH structure. In order to select among the different model specifications and distributions, we focus on the largest log likelihood value and the smallest AIC and BIC criteria. When there is no unanimous match, we select the model with the smallest information criterion, prioritizing the BIC information criteria. With the previous results, we find the best model between different ARMA-GARCH structures with different distributions. In the conditional mean we can select between a AR(1) and no ARMA structure. The order of the GARCH specification is always a $P = Q = 1$, but we select between GARCH and EGARCH specifications. The different distributions of the GARCH structure are Normal Gaussian Distribution, Student t-Distribution, Generalized

---

[35] See Wang and Nguyen Thi (2013): Lamoureux and Lastrapes (1990) point that the ignorance of structural breaks might cause over-estimation of heteroskedasticity and affect the reliability of its application to other analyses. Hansen (2001) maintains that structural breaks are endogenous and determined by the data, so that exogenous determination of the structural break would mislead the model fitted. Also see Fang and Chang (2007).

[36] We also performance the test in Inclan and Tiao (1994) and κ_1 statistic Sansó, Aragó, and Carrion-i-Silvestre (2004) and obtained the same conclusions.

[37] Details on the results are available from the authors upon request.

[38] We estimate an exponential GARCH(1,1,1), except for Greece and Japan, for which the estimated model has been an exponential GARCH(2,1,1), with Generalized Error Distribution during all period.

[39] See Lumsdaine and Ng (1999).

[40] See Table 5 and 4 for the results.

[41] See Engle and Ng (1993).

[42] See Eichengreen, Mody, Nedeljkovic, and Sarno (2012) for the problems that can appear when working with multivariate GARCH model.

Error Distribution and Hansen's Skew-t Distribution.[43]

Table **??** confirms the existence unconditional heteroskedasticity in the first-difference of the bonds. The test concludes that there is at least one structural break in the unconditional variance for 15 out of 22 yields, and no break in 7 out of 21 yields.[44] Therefore, we do not assume heteroskedasticity ad-hoc. Instead, we test for its presence in an endogenous way. The results on the filtered first-differenced data allow us to conclude that the return of the bonds are I(1) non-stationary processes with non-stationary volatility.

4.2 Analysis of the markets integration and strong contagion effect

The strategy to analyze the presence of strong contagion is based on cointegration analysis. We wish to analyze both local and global strong contagion. We define between global and local contagion depending on the cointegration relationships in different sub-sets of countries. If we find multivariate cointegration when selecting a full sample with many variables, then we must understand that there is strong global interdependence. We define strong global contagion when the multivariate cointegration relationships change when we move from quiet period to crisis period. Similarly, we conclude that strong local interdependence exists when the bivariate cointegration is stable in whole period, whereas local strong contagion exists when this bivariate cointegration changes through time.

The starting point of crisis is exogenously determined on August 1st, 2007, a decision that bases on two reasons. First, in order to get a general picture of the situation, we have split the sample in two subsamples (tranquil and turbulent periods) using as the break point the date in which begins the liquidity shortages worldwide and the central banks –mainly the Federal Reserve and the European Central Bank– coordinated efforts to increase the liquidity of the markets. We define tranquil and turbulent periods as stretching from April 1st, 1999 through July 31th, 2007 and from August 1st, 2007 through November 17th, 2014, respectively. These subsamples allow the comparison between periods without worrying about different power of test statistics for each period because they have similar number of observations.

In the previous section, we have shown that the sovereign debt suffers from unconditional volatility. This feature of the data does not allow us to proceed with the strong contagion analysis with the classical cointegration tests. The sequential procedure based on the asymptotic (pseudo-) likelihood ratio test of Johansen (1995) can be significantly upward size distorted in the presence of non-stationary heteroskedasticity. Cavaliere, Rahbek, and Taylor (2010) show that the sequential (pseudo-) likelihood ratio test of Johansen (1995) is no longer valid, even asymptotically, in the

---

[43] The ARMA(1,0)-GARCH(1,1)-GED distribution estimation are for Australia, Austria, Belgium, Denmark, Finland, France, Ireland, Italy, Netherlands, Norway, Spain and Sweden. The ARMA(0,0)-GARCH(1,1)-GED distribution estimation are for Germany, Switzerland, United Kingdom, United States, New Zealand, Canada and Japan. The ARMA(1,0)-EGARCH(1,1)-GED distribution estimation is for Greece. The ARMA(0,0)-EGARCH(1,1)-GED distribution estimation is for Portugal. Finally, The ARMA(1,0)-EGARCH(1,1)-Hansen distribution estimation is for Hungary.

[44] We also performance the test without GARCH structure and arrived at the same conclusions although up to eight structural breaks have been detected, depending on the case.

presence of non-stationary heteroskedasticity.

Then, we compute cointegration tests that are robust to non-stationary unconditional heteroskedasticity.[45] To the best of our knowledge, there is no other contribution in the empirical literature that analyzes financial contagion. Covering this feature, as we have mentioned above, non-stationary volatility has a great influence on cointegration test. In order to overcome this drawback, in this paper, we consider two robust tests. The wild bootstrap implementation of the Johansen (1995) test procedure proposed by Cavaliere, Rahbek, and Taylor (2014) and the BIC semi-parametric variant of information-based method proposed by Cheng and Phillips (2009). In both tests we use the BIC to select the lag length parameter. We have applied both test statistics because it is not clear which test has better relative finite sample properties.[46]

The tests are based on a m-dimensional process $\{X_t\}$ which satisfies a vector-autoregressive model (VAR) of order k written in the error correction form:

$$\Delta X_t = \alpha\beta' X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \alpha\rho' D_t + \phi d_t + \epsilon_t, \qquad t = 1, ..., T, \tag{1}$$

where α and β are $(m \times r_0)$-matrices, and r_0 the unknown cointegrating rank. The error term ϵ_t is assumed to satisfy the assumptions outlined in Cavaliere, Rahbek, and Taylor (2014). The deterministic component in equation (1) is defined according to one of the following cases: (i) $D_t = 0$, $d_t = 0$ (no deterministic component); (ii) $D_t = 1$, $d_t = 0$ (restricted constant); or (iii) $D_t = 1$, $d_t = 1$ (restricted linear trend).[47]

$$\begin{aligned} BIC(k,r) &= T \log |S_{00}^{(k)}| + T \sum_{i=1}^{r} \log(1 - \widehat{\lambda}_i^{(k)}) + (\log T)\pi(k,r) \qquad (2) \\ (\widetilde{k}_{IC}, \widetilde{r}_{IC}) &= \arg \min_{r=0,..p;k=1..,K} IC(k,r). \qquad (3) \end{aligned}$$

The results of Table 8 shows, on the one hand, that there is weak strong local interdependence. Only the 25% of total bivariate cointegration tests find cointegration relationships in the calm period.[48] This strong local interdependence disappears in the crisis period. This soft change indicates that the strong local contagion is weak. On the other hand, looking at the strong global interdependence, we see that the percentage of cointegration relationships among countries increases as the dimension of X_t – i.e., the number of countries considered in the model – gets larger.[49] Notwithstanding, the increase in m does not lead to detect more cointegrating relationships, since the cointegrating rank equals one in all cases. Finally and regarding the global contagion, there

---

[45] Both test are robust of the form considered in Cavaliere, Rahbek, and Taylor (2010).

[46] See Cavaliere, Angelis, Rahbek, and Taylor (2015).

[47] see, e.g. Johansen (1995).

[48] We performed the BIC joint cointegration test in full period to analyze the robustness of our results. We found similar conclusion in full period. It allows us to have a more robust finding.

[49] We performed the BIC joint cointegration test in full period to analyze the robustness of our results. We found similar conclusion in full period. It allows us to have a more robust finding.

is no cointegration relationships in the crisis period, despite of the value of m. Therefore, we can conclude that there is a significant strong global contagion.

4.3 Analysis of fast contagion and Granger causality

After the strong contagion analysis has been carried out, we focus on the study of fast contagion with pairwise Granger causality. The concept of Granger causality implies that the cause cannot come after the effect. Thus, if one variable X_t causes another Y_t, the former should help improving the predictions of the latter variable. In addition, if the second one Y_t also causes the former X_t, (X_t, Y_t) defines a so-called feedback system. The classical Granger causality test of Granger (1969) estimates a bivariate VAR model. This approach allows us to study the short-run dynamics of contagion. There are two Granger causality specifications when the variables are non-stationary.

The first one appears when the variables are non-stationary and non-cointegrated. The Granger causality test is a Wald test that specifies the null hypothesis that $H_0 : \gamma_{x,j} = 0 \ \forall j$ against the alternative hypothesis that $H_1 : \gamma_{x,j} \neq 0$ for some j in the system:

$$\begin{aligned} \Delta X_t &= \alpha_x + \sum_{i=1}^{p-1} \beta_{x,i} \Delta X_{t-i} + \sum_{j=1}^{k-1} \gamma_{x,j} \Delta Y_{t-j} + \epsilon_{1,t} && (4) \\ \Delta Y_t &= \alpha_y + \sum_{i=1}^{p-1} \beta_{y,i} \Delta Y_{t-i} + \sum_{j=1}^{k-1} \gamma_{y,j} \Delta X_{t-j} + \epsilon_{2,t}. && (5) \end{aligned}$$

If the variables are non-stationary but cointegrated, the Wald test is performed on the speed of adjustment coefficient –the parameter of the error correction term Z_t– of the VAR model expressed in an error correction form:

$$\begin{aligned} \Delta X_t &= \alpha_x + \sum_{i=1}^{p-1} \beta_{x,i} \Delta X_{t-i} + \sum_{j=1}^{k-1} \gamma_{x,j} \Delta Y_{t-j} + \psi_x Z_{t-1} + \epsilon_{1,t} && (6) \\ \Delta Y_t &= \alpha_y + \sum_{i=1}^{p-1} \beta_{y,i} \Delta Y_{t-i} + \sum_{j=1}^{k-1} \gamma_{y,j} \Delta X_{t-j} + \psi_y Z_{t-1} + \epsilon_{2,t} && (7) \end{aligned}$$

When there is no cointegration, Granger causality is tested using the system defined by (4) and (5), whereas the system defined by (6) and (7) is used when cointegration is found. The lag length k is chosen by joint IC cointegration test. We select this criteria because the Granger causality test is sensible to the right selection.[50] This approach captures the non-stationary volatility and improves this step that has been used in the literature of Granger causality in financial contagion.

The results are reported in Table 9, for the tranquil period, and in Table 10, for the crisis period. These results point to the presence of fast contagion since the short-run dynamics causality is different in the tranquil and crisis periods. Further, the evidence of weak fast contagion decreases in the crisis period – evidence of Granger causality in the calm period is found in 39% of case, which

---

[50] See Thornton and Batten (1985)

reduces to 23% in the crisis period.

5 Conclusions

The present article contributes to the analysis of European debt crisis and Great recession by stating that the market behavior in such a turbulent period is marked by a change in the short and long term dependence that differs from the ones found in the tranquil period. The analysis is performed using the most industrialized OECD countries, and has led us to conclude that, under the current economic conditions, the strong and fast dependence that link the debt markets of these countries have a unique character that can be associated to financial contagion.

The analysis that has been conducted reveals that the returns of the sovereign debt of OECD countries are non-stationary processes with non-stationary volatility. We use endogenously determined tests to assess the presence of non-stationary volatility.

Our analysis bases on the specification of a common stochastic trend, cointegration and Granger causality analyses, which aim to control the presence of global and local contagions (cross-section dependence) and, strong and fast contagions (cross-section dependence in the long and short terms). Thus, the application of cointegration test statistics has revealed that the long-term or strong dependence that exists in the tranquil period disappears in the crisis period. Further, the short term dependence decreases in the crisis period. These conclusions are important in international investment for international portfolio management and risk assessment. The framework that has been used in this paper, which relies on the use of cointegration and Granger causality analyses– accounts for all possible channels of transmission. In this regard, our approach mitigates the potential drawbacks caused by misspecification errors. However, we cannot ascertain which specific contagion channel is more prevalent in the present study, a question that is out of the scope of this paper. The main contribution of this paper is the robust analysis of unit root, cointegration and Granger causality analysis accounting for the presence of non-stationary volatility, an approach that allows us to overcome the criticism in Forbes and Rigobon (2002).

Table 1: Bootstrap union unit root tests of Smeekes and Taylor (2012)

	Levels					First differenced				
		UR-A		UR-B			UR-A		UR-B	
	Statistic	Value	p-val	Value	p-val	Statistic	Value	p-val	Value	p-val
Austria	-1.607	-2.264	0.356	-2.197	0.330	-23.036	-2.261	0.000	-2.261	0.000
Belgium	-1.433	-2.265	0.516	-2.258	0.506	-27.681	-2.246	0.000	-2.246	0.000
Finland	-1.564	-2.230	0.382	-2.154	0.352	-10.640	-2.327	0.000	-2.327	0.000
France	-1.706	-2.306	0.308	-2.230	0.282	-10.766	-2.289	0.000	-2.289	0.000
Germany	-1.782	-2.268	0.230	-2.184	0.199	-10.795	-2.339	0.000	-2.340	0.000
Greece	-2.026	-3.439	0.246	-3.227	0.256	-58.522	-3.374	0.000	-3.374	0.000
Ireland	-1.416	-2.584	0.558	-2.586	0.558	-30.973	-2.566	0.000	-2.566	0.000
Italy	-1.683	-2.457	0.334	-2.461	0.334	-41.262	-2.458	0.000	-2.458	0.000
Netherlands	-1.662	-2.254	0.314	-2.181	0.278	-32.789	-2.272	0.000	-2.272	0.000
Portugal	-1.143	-2.721	0.705	-2.653	0.713	-38.244	-2.713	0.000	-2.714	0.000
Spain	-1.634	-2.464	0.390	-2.458	0.390	-51.671	-2.423	0.000	-2.423	0.000
Denmark	-1.563	-2.281	0.391	-2.170	0.352	-10.276	-2.307	0.000	-2.308	0.000
Norway	-1.774	-2.269	0.238	-2.178	0.199	-11.536	-2.315	0.000	-2.314	0.000
Sweden	-1.924	-2.221	0.146	-2.154	0.119	-10.966	-2.316	0.000	-2.316	0.000
United Kingdom	-1.742	-2.281	0.268	-2.219	0.248	-61.349	-2.307	0.000	-2.307	0.000
Hungary	-1.906	-2.276	0.156	-2.264	0.159	-44.566	-2.296	0.000	-2.296	0.000
Switzerland	-1.786	-2.286	0.254	-2.227	0.224	-30.465	-2.274	0.000	-2.274	0.000
Australia	-1.697	-2.290	0.307	-2.259	0.296	-69.810	-2.290	0.000	-2.290	0.000
New Zealand	-1.816	-2.279	0.224	-2.223	0.202	-10.791	-2.345	0.000	-2.345	0.000
Canada	-2.476	-2.230	0.019	-2.146	0.012	-63.771	-2.270	0.000	-2.270	0.000
United States	-1.977	-2.299	0.146	-2.257	0.129	-12.993	-2.327	0.000	-2.328	0.000
Japan	-1.879	-2.296	0.194	-2.295	0.189	-9.675	-2.288	0.000	-2.288	0.000

Note: Value indicates rejection of the corresponding null hypothesis at 5 % level of significance

Table 2: Descriptive statistics of first difference of the bonds

		Mean	**Median**	**Standard deviation**	**Skewness**	**Kurtosis**
Austria	**Statistic**	-0.00	0.00	0.04	0.38	5.36
	P-Value	-0.00	-0.00	0.05	0.20	7.82
Belgium	**Statistic**	-0.00	-0.00	0.04	0.22	4.79
	P-Value	-0.00	0.00	0.04	0.16	5.99
Finland	**Statistic**	-0.00	-0.00	0.04	0.12	4.57
	P-Value	0.00	0.00	0.50	-40.98	2323.88
France	**Statistic**	-0.00	-0.00	0.07	-0.14	34.31
	P-Value	-0.00	-0.00	0.06	-0.83	25.44
Germany	**Statistic**	-0.00	0.00	0.04	0.20	4.29
	P-Value	-0.00	0.00	0.10	1.30	58.27
Greece	**Statistic**	-0.00	-0.00	0.06	-1.09	22.18
	P-Value	-0.00	0.00	0.04	0.15	6.47
Ireland	**Statistic**	-0.00	0.00	0.05	0.16	6.53
	P-Value	-0.00	0.00	0.04	0.10	5.43
Italy	**Statistic**	-0.00	0.00	0.05	0.09	4.95
	P-Value	-0.00	0.00	0.12	3.55	97.09
Netherlands	**Statistic**	-0.00	-0.00	0.04	0.04	9.27
	P-Value	-0.00	0.00	0.07	0.05	5.58
Portugal	**Statistic**	-0.00	0.00	0.05	0.31	7.02
	P-Value	-0.00	0.00	0.05	0.17	4.26
Spain	**Statistic**	-0.00	0.00	0.06	0.06	5.36
	P-Value	-0.00	0.00	0.03	0.42	7.42

Table 3: Ljung-Box Q test on the squared residuals regressed on q lags and a constant for whole period

	LAG	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Austria	**Statistic**	36.36	59.52	193.45	226.45	274.10	381.15	413.73	448.16	510.51	531.16
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Belgium	**Statistic**	638.00	981.65	1307.86	1622.95	2101.68	2512.45	2747.43	2843.47	2897.62	3014.94
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Finland	**Statistic**	26.57	51.33	76.81	103.94	134.49	165.99	190.24	212.38	228.16	254.98
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
France	**Statistic**	70.21	128.60	298.01	327.82	396.87	487.84	540.27	575.42	621.41	657.48
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Germany	**Statistic**	40.22	62.14	104.00	131.05	188.61	247.73	273.34	322.62	353.08	406.05
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greece	**Statistic**	0.35	0.51	17.75	17.91	17.91	17.91	17.92	17.92	17.97	17.97
	P-Value	0.55	0.77	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.06
Ireland	**Statistic**	266.33	515.07	634.69	741.63	924.28	1055.09	1141.59	1230.97	1356.94	1529.23
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Italy	**Statistic**	48.98	243.39	349.02	403.49	437.75	466.70	488.38	517.18	531.12	572.89

Note: Under the null of no serial correlation, the test statistic is asymptotically distributed as a χ^2_q

Continued on next page

Table 3 – continued from previous page

	LAG	1	2	3	4	5	6	7	8	9	10
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands	**Statistic**	39.38	61.91	90.81	123.84	144.38	179.88	201.43	230.61	267.63	317.90
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Portugal	**Statistic**	87.42	168.20	198.19	285.59	311.55	340.36	361.05	391.12	426.83	577.41
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spain	**Statistic**	63.49	117.97	158.64	233.55	263.09	278.89	305.93	326.45	353.74	393.15
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Denmark	**Statistic**	52.15	60.55	110.89	119.06	125.51	136.14	157.88	191.96	212.29	227.75
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Norway	**Statistic**	64.69	99.02	128.62	173.24	211.62	287.28	318.92	328.09	348.76	368.36
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sweden	**Statistic**	106.35	126.24	152.90	205.25	226.84	255.60	263.97	277.55	291.94	310.88
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Kingdom	**Statistic**	110.79	125.41	134.84	158.32	212.17	247.74	275.68	284.51	300.47	352.99
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	**Statistic**	0.19	0.21	1.05	1.06	1.53	1.54	1.55	2.53	2.53	2.57
	P-Value	0.66	0.90	0.79	0.90	0.91	0.96	0.98	0.96	0.98	0.99
Switzerland	**Statistic**	15.80	26.23	30.90	36.12	41.41	49.14	58.78	69.42	82.71	120.93

Note: Under the null of no serial correlation, the test statistic is asymptotically distributed as a χ_q^2

Continued on next page

Table 3 – continued from previous page

	LAG	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Australia	**Statistic**	114.69	146.44	179.32	199.68	213.85	228.35	241.03	250.56	283.65	297.48
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Zealand	**Statistic**	73.77	87.91	105.56	110.17	117.05	122.19	124.38	126.01	131.52	139.53
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	**Statistic**	42.06	72.03	86.96	158.40	180.98	193.87	219.23	236.36	241.58	275.19
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United States	**Statistic**	25.49	55.33	80.14	155.93	205.43	237.06	267.16	277.70	327.29	360.50
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Japan	**Statistic**	119.10	179.20	343.87	404.31	472.02	525.39	601.30	646.39	717.70	870.39
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4: LM test of the residuals regressed on q lags and a constant for whole period

	LAG	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Austria	**Statistic**	24.60	25.11	26.96	26.96	37.10	37.35	38.99	39.34	46.73	48.98
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Belgium	**Statistic**	96.32	96.98	104.74	104.77	116.34	116.79	117.05	117.39	117.47	117.59
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Finland	**Statistic**	9.68	10.42	16.61	17.95	19.17	19.30	19.35	19.44	19.86	19.92
	P-Value	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03
France	**Statistic**	3.42	6.29	6.75	7.26	11.59	12.19	13.64	13.66	17.55	18.19
	P-Value	0.06	0.04	0.08	0.12	0.04	0.06	0.06	0.09	0.04	0.05
Germany	**Statistic**	17.64	18.56	20.60	22.18	22.50	23.07	25.14	25.65	26.06	26.35
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greece	**Statistic**	29.65	41.62	165.15	194.82	199.99	204.58	230.44	232.18	244.75	247.79
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ireland	**Statistic**	180.06	198.48	205.31	211.38	215.81	217.49	217.42	221.94	228.40	228.67
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Italy	**Statistic**	50.68	60.34	67.95	70.70	81.03	81.19	83.56	84.64	84.79	84.94

Note: Under the null of no serial correlation, the test statistic is asymptotically distributed as a χ^2_q

Continued on next page

Table 4 – continued from previous page

	LAG	1	2	3	4	5	6	7	8	9	10
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands	**Statistic**	20.79	20.95	24.25	25.98	26.94	27.25	28.59	28.75	29.04	29.16
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Portugal	**Statistic**	209.95	215.22	215.73	250.87	251.65	258.86	262.45	263.44	277.29	278.18
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spain	**Statistic**	174.74	180.44	202.06	214.52	221.54	223.18	225.08	225.02	226.02	227.07
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Denmark	**Statistic**	34.93	36.88	37.62	37.51	38.33	38.38	38.51	41.32	43.58	45.71
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Norway	**Statistic**	36.35	41.69	43.87	46.73	50.17	55.54	57.19	57.63	62.05	67.20
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sweden	**Statistic**	42.32	42.35	43.71	43.48	45.70	46.82	49.96	50.50	50.48	50.49
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Kingdom	**Statistic**	6.42	8.17	13.44	14.96	16.45	17.49	21.22	21.47	24.33	25.81
	P-Value	0.01	0.02	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
Hungary	**Statistic**	2.70	2.70	2.73	5.72	9.25	11.36	12.21	12.18	12.24	12.40
	P-Value	0.10	0.26	0.43	0.22	0.10	0.08	0.09	0.14	0.20	0.26
Switzerland	**Statistic**	1.49	2.94	5.33	6.08	9.53	10.64	15.92	15.98	16.26	16.69

Note: Under the null of no serial correlation, the test statistic is asymptotically distributed as a χ_q^2

Continued on next page

Table 4 – continued from previous page

	LAG	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	P-Value	0.22	0.23	0.15	0.19	0.09	0.10	0.03	0.04	0.06	0.08
Australia	**Statistic**	32.45	37.21	39.31	39.53	39.57	40.33	40.48	40.19	42.14	42.48
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Zealand	**Statistic**	1.33	4.16	4.16	4.12	4.38	4.51	4.93	5.13	5.30	6.40
	P-Value	0.25	0.13	0.24	0.39	0.50	0.61	0.67	0.74	0.81	0.78
Canada	**Statistic**	0.00	7.48	7.51	7.43	8.73	8.81	9.97	10.19	10.24	10.84
	P-Value	0.95	0.02	0.06	0.11	0.12	0.18	0.19	0.25	0.33	0.37
United States	**Statistic**	0.00	8.92	9.26	9.39	10.56	11.00	13.12	13.82	13.87	15.06
	P-Value	0.96	0.01	0.03	0.05	0.06	0.09	0.07	0.09	0.13	0.13
Japan	**Statistic**	0.05	1.54	3.73	8.68	10.48	10.75	11.16	13.52	16.98	22.64
	P-Value	0.83	0.46	0.29	0.07	0.06	0.10	0.13	0.10	0.05	0.01

Table 5: Engle LM test of the squared residuals regressed on q lags and a constant for whole period

	LAG	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Austria	**Statistic**	36.31	54.36	171.16	184.36	208.26	261.57	268.29	274.73	288.98	289.75
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Belgium	**Statistic**	637.62	723.87	799.14	849.15	969.92	1007.11	1007.32	1021.55	1034.96	1037.58
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Finland	**Statistic**	26.52	47.33	66.04	83.61	101.63	118.29	127.99	135.51	139.01	148.37
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
France	**Statistic**	70.13	113.52	243.33	247.68	275.42	305.93	319.08	321.04	326.81	330.25
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Germany	**Statistic**	40.15	56.60	88.61	103.33	140.52	172.21	179.00	199.16	205.71	224.88
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greece	**Statistic**	0.35	0.51	17.66	17.76	17.76	17.81	17.80	17.80	17.85	17.84
	P-Value	0.55	0.78	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.06
Ireland	**Statistic**	266.19	409.93	432.49	451.71	516.12	534.66	536.88	544.18	568.11	601.32
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Italy	**Statistic**	48.95	224.48	285.54	295.89	298.05	300.77	303.01	309.29	310.02	322.99

Note: Under the null of no serial correlation, the test statistic is asymptotically distributed as a χ^2_q

Continued on next page

Table 5 – continued from previous page

	LAG	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands	**Statistic**	39.31	56.40	77.41	98.46	107.58	126.99	134.24	145.99	161.14	182.86
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Portugal	**Statistic**	87.37	146.60	157.04	210.20	214.45	220.16	224.05	230.88	241.85	330.06
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spain	**Statistic**	63.46	104.83	127.82	173.96	181.68	183.34	191.25	194.83	202.48	217.12
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Denmark	**Statistic**	52.09	56.40	99.72	101.41	104.13	108.20	121.38	141.09	148.35	152.43
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Norway	**Statistic**	64.62	88.37	105.88	132.87	150.49	193.22	200.43	200.39	204.62	207.26
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sweden	**Statistic**	106.23	114.13	130.65	163.36	168.64	181.53	181.50	185.05	188.41	193.73
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Kingdom	**Statistic**	110.68	115.05	120.16	136.12	170.27	183.02	192.97	193.59	198.43	224.02
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	**Statistic**	0.19	0.21	1.05	1.05	1.57	1.53	1.55	2.43	2.44	2.49
	P-Value	0.66	0.90	0.79	0.90	0.90	0.96	0.98	0.96	0.98	0.99
Switzerland	**Statistic**	15.78	24.66	27.83	31.46	34.95	40.25	46.56	53.05	61.04	88.76

Note: Under the null of no serial correlation, the test statistic is asymptotically distributed as a χ_q^2

Continued on next page

Table 5 – continued from previous page

	LAG	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Australia	**Statistic**	114.62	129.65	148.04	155.33	159.43	164.12	167.58	169.61	187.22	189.02
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Zealand	**Statistic**	73.71	80.54	92.13	93.18	96.74	98.57	99.01	99.34	102.41	106.39
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	**Statistic**	41.99	65.52	73.81	129.75	138.21	141.06	152.84	156.42	156.57	174.29
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United States	**Statistic**	25.45	51.29	68.98	128.03	156.69	168.90	179.10	179.33	199.04	208.14
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Japan	**Statistic**	119.08	154.72	271.22	284.89	309.63	315.92	338.99	344.05	362.11	418.71
	P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6: Sign Size Bias Test

Country	**SB test**	**p-value**	**NSB test**	**p-value**	**PSB test**	**p-value**	**General test**	**p-value**
Austria	-3.100	0.001	-25.376	0.000	84.123	0.000	3280.253	0.000
Belgium	-1.625	0.052	-30.056	0.000	71.577	0.000	3098.919	0.000
Finland	-2.196	0.014	-29.428	0.000	69.130	0.000	3309.027	0.000
France	-1.194	0.116	-32.493	0.000	64.679	0.000	3168.612	0.000
Germany	-1.933	0.027	-32.619	0.000	59.646	0.000	3324.589	0.000
Greece	0.864	0.194	-169.306	0.000	5.835	0.000	3621.422	0.000
Ireland	-0.369	0.356	-42.667	0.000	49.963	0.000	2701.670	0.000
Italy	0.096	0.462	-46.562	0.000	34.535	0.000	2587.971	0.000
Netherlands	-2.148	0.016	-29.967	0.000	65.995	0.000	3400.647	0.000
Portugal	-0.713	0.238	-27.757	0.000	93.396	0.000	2685.158	0.000
Spain	0.423	0.336	-48.803	0.000	25.294	0.000	2521.390	0.000
Denmark	-1.115	0.132	-32.522	0.000	64.669	0.000	3069.229	0.000
Norway	-1.449	0.074	-33.609	0.000	67.781	0.000	3180.289	0.000
Sweden	-1.340	0.090	-31.772	0.000	63.566	0.000	3095.359	0.000
United Kingdom	-1.392	0.082	-33.448	0.000	58.857	0.000	3240.707	0.000
Hungary	2.902	0.002	-15.913	0.000	204.256	0.000	2332.288	0.000
Switzerland	-0.850	0.198	-34.261	0.000	50.383	0.000	2692.456	0.000
Australia	0.011	0.496	-32.225	0.000	66.056	0.000	3123.760	0.000
New Zealand	-0.865	0.194	-28.162	0.000	79.016	0.000	3038.556	0.000
Canada	-1.722	0.043	-31.117	0.000	66.511	0.000	3402.927	0.000
United States	-1.557	0.060	-34.255	0.000	54.090	0.000	3117.325	0.000
Japan	-2.701	0.003	-26.119	0.000	87.708	0.000	3090.553	0.000

Note: Sign Bias (SB), Negative Size Bias (NSB), Positive Size Bias (PSB) tests and general test for asymmetric volatility. The test are applied to the residuals from an AR(K) model, with K determined by the AIC.

Table 7: Sansó et al (2004)

Country	**Number of breaks**	**Break positions**						
Austria	0							
Belgium	0							
Finland	0							
France	3	02/03/2004	06/10/2008	08/10/2009				
Germany	5	02/03/2004	24/01/2008	29/09/2008	22/07/2009	26/12/2012		
Greece	5	24/01/2008	19/11/2009	18/04/2011	30/11/2012	18/09/2013		
Ireland	2	10/05/2010	13/04/2012					
Italy	2	11/07/2011	27/11/2012					
Netherlands	0							
Portugal	2	10/05/2010	29/10/2013					
Spain	6	30/06/1999	24/03/2000	24/01/2008	08/08/2011	20/11/2012	13/08/2013	
Denmark	3	22/10/2004	30/01/2008	31/12/2012				
Norway	0							
Sweden	3	25/06/2004	23/01/2008	17/12/2012				
United Kingdom	7	04/11/1999	21/11/2000	07/12/2001	28/12/2004	12/12/2007	13/10/2008	09/12/2009
Hungary	0							
Switzerland	0							
Australia	6	16/07/2004	14/11/2007	13/10/2008	05/03/2010	08/08/2011	01/01/2013	
New Zealand	3	24/11/2004	17/07/2008	31/12/2009				
Canada	3	08/11/2004	13/12/2007	12/03/2012				
United States	4	03/02/2005	13/12/2007	26/11/2009	16/05/2012			
Japan	4	06/11/2001	19/06/2003	18/03/2009	06/09/2010			

Note: We use the κ_2 test (corrects for non-mesokurtosis and persistence in conditional variance), using the spectral quadratic window and automatic bandwidth selection.

Table 8: Percentage of one cointegration vector $\{r = 1\}$ using the joint procedure

Multivariate cointegration test	**Bivariate**	**Trivariate**	**4th**	**5th**	**6th**
Calm period	25%	52%	63%	74%	89%
Crisis period	0	0	0	0	0
Number of combinations	231	1540	7315	26334	74613

Note: The rejection of the corresponding null hypothesis is at 5 % level of significance

Table 9: Granger causality tranquil period

	AT	**BE**	**FI**	**FR**	**DE**	**GR**	**IR**	**IT**	**NL**	**PT**	**ES**	**DK**	**NO**	**SE**	**UK**	**HU**	**CH**	**AU**	**NZ**	**CA**	**US**	**JP**
Austria		NaN	NaN	NaN	0.00	0.04	0.04	0.01	0.00	NaN	NaN	0.00	NaN	0.00	NaN	NaN	NaN	NaN	NaN	0.00	0.00	NaN
Belgium	NaN		0.05	NaN	0.00	0.00	0.00	0.00	0.00	NaN	NaN	0.00	0.04	0.01	NaN	NaN	NaN	NaN	NaN	0.00	0.00	NaN
Finland	NaN	0.00		0.03	0.00	0.00	0.03	0.00	0.00	NaN	NaN	0.00	NaN	0.01	NaN	NaN	0.02	NaN	NaN	0.00	0.00	NaN
France	NaN	NaN	NaN		0.00	0.00	NaN	0.00	0.00	NaN	NaN	0.00	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.00	0.00	NaN
Germany	NaN	NaN	NaN	NaN		0.00	NaN	NaN	0.00	NaN	NaN	0.00	NaN	0.00	NaN	NaN	0.04	NaN	NaN	0.00	0.00	NaN
Greece	0.02	NaN	NaN	0.01	0.00		0.00	0.01	0.00	NaN	NaN	0.00	NaN	NaN	NaN	NaN	0.03	NaN	NaN	0.02	0.00	NaN
Ireland	NaN	NaN	NaN	NaN	0.00	0.00		0.00	0.00	NaN	0.01	0.00	0.04	NaN	0.01	NaN	0.03	0.05	NaN	0.01	0.00	NaN
Italy	0.01	NaN	NaN	NaN	0.00	0.00	0.01		0.00	NaN	NaN	0.00	NaN	NaN	NaN	NaN	0.01	NaN	NaN	0.00	0.00	NaN
Netherlands	NaN	NaN	NaN	NaN	0.00	0.01	NaN	0.00		NaN	NaN	0.00	NaN	0.04	0.03	NaN	0.02	NaN	NaN	0.00	0.00	NaN
Portugal	NaN	NaN	0.03	NaN	0.00	0.01	0.00	0.00	0.00		0.00	0.00	NaN	NaN	0.00	NaN	0.01	NaN	NaN	0.01	0.00	0.03
Spain	NaN	NaN	NaN	NaN	0.00	0.00	NaN	0.00	0.00	NaN		0.00	0.03	0.01	NaN	NaN	0.01	NaN	NaN	0.00	0.00	NaN
Denmark	NaN	NaN	0.00	NaN	NaN	NaN	0.02	0.01	0.00	NaN	NaN		NaN	NaN	NaN	NaN	0.01	0.00	NaN	0.00	0.00	NaN
Norway	NaN	NaN	0.03	0.03	NaN	0.01	0.03	NaN	0.00	NaN	NaN	0.01		NaN	NaN	NaN	NaN	NaN	NaN	0.00	0.00	NaN
Sweden	NaN	NaN	NaN	0.04	0.01	0.00	NaN	NaN	0.00	NaN	NaN	NaN	NaN		NaN	NaN	0.00	NaN	NaN	0.00	0.00	NaN
United Kingdom	NaN	NaN	0.00	NaN	NaN	0.00	0.00	NaN	0.03	NaN	0.00	0.04	NaN	0.01		NaN	NaN	NaN	NaN	0.00	0.00	NaN
Hungary	0.01	NaN	NaN	0.02	0.00	NaN	NaN	NaN	0.02	NaN	0.04	NaN	NaN	0.04	NaN		NaN	NaN	NaN	NaN	0.01	NaN
Switzerland	0.02	NaN	NaN	NaN	0.02	0.00	NaN	0.01	NaN	0.05	NaN	0.01	0.00	NaN	NaN	NaN		NaN	0.05	0.00	0.00	NaN
Australia	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.00	0.00	0.00	NaN	NaN		NaN	0.00	0.00	0.01
New Zealand	NaN	NaN	NaN	NaN	NaN	NaN	0.02	0.00	NaN	NaN	NaN	0.00	NaN	NaN	NaN	NaN	NaN	0.00		0.00	0.00	NaN
Canada	NaN	NaN	NaN	NaN	0.03	0.00	0.01	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN		0.00	NaN
UnitedStates	NaN	NaN	NaN	NaN	0.04	0.00	0.02	NaN	NaN	NaN	0.02	NaN	NaN	NaN	NaN	NaN	0.02	NaN	NaN	0.00		NaN
Japan	NaN	NaN	NaN	NaN	NaN	0.02	NaN	NaN	NaN	NaN	NaN	0.05	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.00	

Note: NaN indicates rejection of the corresponding null hypothesis at 5 % level of significance

Table 10: Granger causality crisis period

	AT	BE	FI	FR	DE	GR	IR	IT	NL	PT	ES	DK	NO	SE	UK	HU	CH	AU	NZ	CA	US	JP
Austria		0.00	NaN	0.01	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.00	NaN	0.04	NaN	NaN	NaN	NaN
Belgium	0.00		0.03	0.00	NaN	NaN	NaN	0.00	NaN	0.00	0.00	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Finland	0.04	0.00		0.04	0.00	NaN	NaN	0.00	NaN	NaN	0.00	0.00	NaN	NaN	NaN	NaN	NaN	0.00	NaN	0.03	NaN	NaN
France	NaN	0.00	NaN		0.03	NaN	NaN	0.02	NaN	NaN	0.01	NaN	NaN	NaN	NaN	0.05	NaN	NaN	NaN	0.05	0.01	NaN
Germany	NaN	0.01	NaN	NaN		0.02	NaN	0.04	NaN	NaN	0.03	0.00	NaN	NaN	NaN	NaN	NaN	0.00	NaN	0.02	0.00	NaN
Greece	NaN	NaN	NaN	NaN	NaN		NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Ireland	0.01	0.00	0.01	0.02	NaN	NaN		NaN	NaN	NaN	NaN	0.05	NaN	NaN	0.02	0.05	NaN	NaN	NaN	NaN	NaN	NaN
Italy	0.02	NaN	NaN	0.00	NaN	NaN	0.02		NaN	0.00	0.02	0.03	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Netherlands	NaN	0.02	NaN	NaN	0.01	0.03	NaN	NaN		NaN	NaN	0.01	NaN	NaN	NaN	NaN	NaN	0.01	NaN	0.00	NaN	NaN
Portugal	NaN	0.04	NaN	NaN	NaN	NaN	NaN	NaN	NaN		NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Spain	NaN	NaN	NaN	0.00	NaN	NaN	NaN	0.00	NaN	0.00		NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Denmark	NaN	0.05	NaN	NaN	NaN	0.04	NaN	0.00	NaN	NaN	NaN		NaN	NaN	NaN	NaN	NaN	0.00	NaN	0.00	0.01	NaN
Norway	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.02	NaN	0.00	NaN	NaN		NaN	NaN	NaN	NaN	0.00	NaN	0.01	0.01	NaN
Sweden	NaN	NaN	NaN	NaN	NaN	0.03	NaN	NaN	NaN	NaN	NaN	NaN	NaN		NaN	NaN	NaN	0.00	NaN	0.01	0.00	NaN
UnitedKingdom	NaN	NaN	NaN	NaN	NaN	0.00	NaN	NaN	0.04	NaN	NaN	NaN	NaN	NaN		NaN	NaN	0.01	0.03	0.00	0.00	NaN
Hungary	NaN	NaN	NaN	0.04	NaN	NaN	NaN	0.03	0.04	NaN	NaN	NaN	0.01	NaN	NaN		NaN	NaN	NaN	0.02	NaN	NaN
Switzerland	NaN	NaN	NaN	NaN	NaN	0.01	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN		0.02	NaN	0.01	0.00	NaN
Australia	0.04	0.01	NaN	NaN	NaN	0.02	NaN	NaN	NaN	NaN	NaN	NaN	0.01	NaN	NaN	NaN	0.00		NaN	0.01	0.00	NaN
NewZealand	NaN	0.00	NaN	NaN	NaN	NaN	NaN	0.00	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.01		0.00	0.00	NaN
Canada	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.00	NaN	NaN	NaN	NaN	NaN	0.00	0.02		NaN	NaN
UnitedStates	NaN	NaN	NaN	NaN	NaN	0.03	NaN	NaN	NaN	NaN	NaN	0.02	NaN	NaN	NaN	NaN	NaN	0.01	NaN	0.00		NaN
Japan	NaN	NaN	0.05	NaN	NaN	NaN	NaN	NaN	0.03	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.00	NaN	NaN	0.00	

Note: NaN indicates rejection of the corresponding null hypothesis at 5 % level of significance

References

AuYong, H. H., C. Gan, and S. Treepongkaruna (2004): "Cointegration and causality in the Asian and emerging foreign exchange markets: Evidence from the 1990s financial crises," *International Review of Financial Analysis*, 13(4), 479–515.

Basse, T. (2014): "Searching for the EMU core member countries," *European Journal of Political Economy*, 34, S32–S39.

Baur, D. G., and R. A. Fry (2009): "Multivariate contagion and interdependence," *Journal of Asian Economics*, 20(4), 353–366.

Bekaert, G., M. Ehrmann, M. Fratzscher, and A. J. Mehl (2011): "Global crises and equity market contagion," Discussion paper, National Bureau of Economic Research.

Bekaert, G., C. R. Harvey, and A. Ng (2005): "Market Integration and Contagion," *Journal of Business*, 78(1).

Belke, A., and R. Setzer (2004): "Contagion, herding and exchange-rate instability–A survey," *Intereconomics*, 39(4), 222–228.

Boyer, B. H., M. S. Gibson, and M. Loretan (1997): *Pitfalls in tests for changes in correlations*, vol. 597. Board of Governors of the Federal Reserve System.

Breuer, J. B. (2004): "An exegesis on currency and banking crises," *Journal of Economic Surveys*, 18(3), 293–320.

Broock, W., J. A. Scheinkman, W. D. Dechert, and B. LeBaron (1996): "A test for independence based on the correlation dimension," *Econometric Reviews*, 15(3), 197–235.

Calomiris, C. W., I. Love, and M. S. M. Peria (2010): "Crisis "shock factors" and the cross-section of global equity returns," Discussion paper, National Bureau of Economic Research.

Carrion-i-Silvestre, J. L., and Ó. Villar (2014): "Dependence and financial contagion in the stock market during the great recession," .

Cashin, P. A., and C. J. McDermott (1995): "International integration of equity markets and contagion effects," .

Cavaliere, G. (2003): "Asymptotics for unit root tests under Markov regime-switching," *The Econometrics Journal*, 6(1), 193–216.

Cavaliere, G., L. D. Angelis, A. Rahbek, and A. R. Taylor (2015): "Determining the Co-integration Rank in Heteroskedastic VAR Models of Unknown Order," .

Cavaliere, G., A. Rahbek, and A. R. Taylor (2010): "Testing for co-integration in vector autoregressions with non-stationary volatility," *Journal of Econometrics*, 158(1), 7–24.

——— (2014): "Bootstrap determination of the co-integration rank in heteroskedastic VAR models," *Econometric Reviews*, 33(5-6), 606–650.

Cavaliere, G., and A. Taylor (2008): "Bootstrap unit root tests for time series with nonstationary volatility," *Econometric Theory*, 24(1), 43–71.

Cheng, X., and P. C. Phillips (2009): "Semiparametric cointegrating rank selection," *The Econometrics Journal*, 12(s1), S83–S104.

Clare, A. D., M. Maras, and S. H. Thomas (1995): “The integration and efficiency of international bond markets,” *Journal of Business Finance & Accounting*, 22(2), 313–322.

Corhay, A., A. T. Rad, and J.-P. Urbain (1993): “Common stochastic trends in European stock markets,” *Economics Letters*, 42(4), 385–390.

Corsetti, G., M. Pericoli, and M. Sbracia (2005): “"Some contagion, some interdependence": More pitfalls in tests of financial contagion,” *Journal of International Money and Finance*, 24(8), 1177–1199.

Darrat, A. F., and M. Zhong (2002): “Permanent and Transitory Driving Forces in the Asian-Pacific Stock Markets,” *Financial Review*, 37(1), 35–51.

De Bandt, O., and P. Hartmann (2000): “Systemic risk: A survey,” Working Paper Series 0035, European Central Bank.

De Santis, R. A. (2012): “The Euro area sovereign debt crisis: safe haven, credit rating agencies and the spread of the fever from Greece, Ireland and Portugal,” .

Dornbusch, R., Y. C. Park, and S. Claessens (2000): “Contagion: understanding how it spreads,” *The World Bank Research Observer*, 15(2), 177–197.

Dungey, M., and D. Gajurel (2014): “Equity market contagion during the global financial crisis: Evidence from the world’s eight largest economies,” *Economic Systems*, 38(2), 161–177.

Dungey, M., V. L. Martin, and A. R. Pagan (2000): “A multivariate latent factor decomposition of international bond yield spreads,” *Journal of Applied Econometrics*, 15(6), 697–715.

Dwyer, G. P., and M. S. Wallace (1992): “Cointegration and market efficiency,” *Journal of International Money and Finance*, 11(4), 318–327.

Eichengreen, B., A. Mody, M. Nedeljkovic, and L. Sarno (2012): “How the subprime crisis went global: Evidence from bank credit default swap spreads,” *Journal of International Money and Finance*, 31(5), 1299–1318.

Engle, R. F. (1982): “A general approach to Lagrange multiplier model diagnostics,” *Journal of Econometrics*, 20(1), 83–104.

Engle, R. F., and V. K. Ng (1993): “Measuring and testing the impact of news on volatility,” *The journal of finance*, 48(5), 1749–1778.

Fang, W.-S., and T.-Y. Chang (2007): “Greater China Equity Funds and Contagion Risk,” *Third Symposium on Econometric Theory and Applications*.

Fofana, L., and F. Seyte (2012): “Modeling financial contagion: approach-based on asymmetric cointegration,” Discussion paper.

Forbes, K. (2012): “The "big C": Identifying contagion,” Discussion paper, National Bureau of Economic Research.

Forbes, K., and R. Rigobon (2001): “Measuring contagion: conceptual and empirical issues,” in *International financial contagion*, pp. 43–66. Springer.

Forbes, K. J., and R. Rigobon (2002): “No contagion, only interdependence: measuring stock market comovements,” *The journal of finance*, 57(5), 2223–2261.

Fratzscher, M. (2012): "Capital flows, push versus pull factors and the global financial crisis," *Journal of International Economics*, 88(2), 341–356.

Gentile, M., and L. Giordano (2012): "Financial contagion during Lehman default and sovereign debt crisis," *Quaderni di Finanza CONSOB*, 72, 3–46.

Giordano, R., M. Pericoli, and P. Tommasino (2013): "Pure or Wake-up-Call Contagion? Another Look at the EMU Sovereign Debt Crisis," *International Finance*, 16(2), 131–160.

Gómez-Puig, M., and S. Sosvilla-Rivero (2014): "Causality and contagion in EMU sovereign debt markets," *International Review of Economics & Finance*, 33, 12–27.

Gómez-Puig, M., and S. Sosvilla Rivero (2014): "EMU sovereign debt market crisis: Fundamentals-based or pure contagion?," *Research Institute of Applied Economics Working Paper*, (2014/02).

Granger, C. W. (1969): "Investigating causal relations by econometric models and cross-spectral methods," *Econometrica: Journal of the Econometric Society*, pp. 424–438.

Granger, C. W. (1986): "Developments in the study of cointegrated economic variables," *Oxford Bulletin of economics and statistics*, 48(3), 213–228.

Hamori, S., and A. Tokihisa (1997): "Testing for a unit root in the presence of a variance shift," *Economics Letters*, 57(3), 245–253.

Hansen, B. E. (2001): "The new econometrics of structural change: Dating breaks in US labor productivity," *Journal of Economic perspectives*, 15(4), 117–128.

Hansen, E., and A. Rahbek (1998): "Stationarity and asymptotics of multivariate ARCH time series with an application to robustness of cointegration analysis," *Department of Theoretical Statistics, University of Copenhagen*, Preprint(12).

Inclan, C., and G. C. Tiao (1994): "Use of cumulative sums of squares for retrospective detection of changes of variance," *Journal of the American Statistical Association*, 89(427), 913–923.

Johansen, S. (1995): "Likelihood-based inference in cointegrated vector autoregressive models," *OUP Catalogue*.

Kasa, K. (1992): "Common stochastic trends in international stock markets," *Journal of Monetary Economics*, 29(1), 95–124.

Khalid, A. M., and M. Kawai (2003): "Was financial market contagion the source of economic crisis in Asia?: Evidence using a multivariate VAR model," *Journal of Asian Economics*, 14(1), 131–156.

Kim, T.-H., S. Leybourne, and P. Newbold (2002): "Unit root tests with a break in innovation variance," *Journal of Econometrics*, 109(2), 365–387.

Lamoureux, C. G., and W. D. Lastrapes (1990): "Heteroskedasticity in stock return data: Volume versus GARCH effects," *The Journal of Finance*, 45(1), 221–229.

Lee, Y.-H., A. L. Tucker, D. K. Wang, and H.-T. Pao (2014): "Global contagion of market sentiment during the US subprime crisis," *Global Finance Journal*, 25(1), 17–26.

Ling, S., W. Li, and M. McAleer (2003): "Estimation and testing for unit root processes with GARCH (1, 1) errors: theory and Monte Carlo evidence," *Econometric Reviews*, 22(2), 179–202.

Longin, F., and B. Solnik (1995): “Is the correlation in international equity returns constant: 1960–1990?,” *Journal of international money and finance*, 14(1), 3–26.

Lumsdaine, R. L., and S. Ng (1999): “Testing for ARCH in the presence of a possibly misspecified conditional mean,” *Journal of Econometrics*, 93(2), 257–279.

Malliaris, A. G., and J. L. Urrutia (1992): “The international crash of October 1987: causality tests,” *Journal of Financial and Quantitative Analysis*, 27(03), 353–364.

Markose, S., S. Giansante, M. Gatkowski, and A. R. Shaghaghi (2009): “Too interconnected to fail: Financial contagion and systemic risk in network model of cds and other credit enhancement obligations of us banks,” *analysis*.

Masson, P. R. (1998): *Contagion-monsoonal effects, spillovers, and jumps between multiple equilibria.* International Monetary Fund.

Mollah, S., and T. Hartman (2012): “Stock Market Contagion, Interdependence and Shifts in Relationship due to Financial Crisis–A Survey,” *International Review of Business Research Papers*, 8(1), 166–195.

Pascual, A. G. (2003): “Assessing European stock markets (co) integration,” *Economics Letters*, 78(2), 197–203.

Pericoli, M., and M. Sbracia (2003): “A primer on financial contagion,” *Journal of Economic Surveys*, 17(4), 571–608.

Rangvid, J. (2001): “Increasing convergence among European stock markets?: A recursive common stochastic trends analysis,” *Economics Letters*, 71(3), 383–389.

Richards, A. J. (1995): “Comovements in national stock market returns: Evidence of predictability, but not cointegration,” *Journal of monetary Economics*, 36(3), 631–654.

Rigobon, R. (2003): “On the measurement of the international propagation of shocks: is the transmission stable?,” *Journal of International Economics*, 61(2), 261–283.

Sander, H., and S. Kleimeier (2003): “Contagion and causality: an empirical investigation of four Asian crisis episodes,” *Journal of International Financial Markets, Institutions and Money*, 13(2), 171–186.

Sansó, A., V. Aragó, and J. L. Carrion-i-Silvestre (2004): “Testing for changes in the unconditional variance of financial time series,” *Revista de Economía financiera*, 4, 32–53.

Smeekes, S., and A. Taylor (2012): “Bootstrap union tests for unit roots in the presence of nonstationary volatility,” *Econometric Theory*, 28(02), 422–456.

Thornton, D. L., and D. S. Batten (1985): “Lag-length selection and tests of Granger causality between money and income,” *Journal of Money, credit and Banking*, pp. 164–178.

Urich, T., and P. Wachtel (2001): “Financial market responses to monetary policy changes in the 1990s,” *Contemporary Economic Policy*, 19(3), 254–267.

Voronkova, S. (2004): “Equity market integration in Central European emerging markets: A cointegration analysis with shifting regimes,” *International Review of Financial Analysis*, 13(5), 633–647.

Wang, K.-M., and T.-B. Nguyen Thi (2013): “Did China avoid the "Asian flu"? The contagion effect test with dynamic correlation coefficients,” *Quantitative Finance*, 13(3), 471–481.

Yunus, N. (2013): “Contagion in international financial markets: A recursive cointegration approach,” *Journal of Multinational Financial Management*, 23(4), 327–337.