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Financial Contagion during the Lehman Brothers Default and Sovereign Debt Crisis

An Empirical Analysis on Euro Area Bond and Equity Markets

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Abstract

The recent Euro area crisis, which has originally been driven mainly by macroeconomic factors, has had a strong impact also on financial markets leading internationally to what is referred to as contagion. The term «contagion», generally used in contrast to «interdependence», conveys the idea that during financial crisis there might be breaks or anomalies in the international transmission mechanism, arguably reflecting switches across multiple equilibria, market panics unrelated to fundamentals, investors' herding and the like. Our study extends on these conventional measures of contagion by directly investigating changes in the existence and the directions of causality links among a sample of Euro area countries during the recent Lehman default and sovereign debt crisis. To test for contagion, we apply Granger causality/VECM methodology on sovereign bond spreads and stock returns as measures of perceived country risk. Results highlight the fact that the causality patterns have changed during the «crisis» periods compared to the pre-crisis «tranquil» periods, thus pointing out the occurrence of contagion phenomenon among Euro area countries during the last two international financial crises.

Keywords: Contagion; Financial Crises; Sovereign Bond Market; Stock Market.
JEL Codes: G01; G15.

1 Introduction

After the stability that characterized the first 10 years of the European Economic and Monetary Union (EMU), the serious tensions that arose in international financial markets in august 2007 due to the US subprime crisis, and the collapse of Lehman Brothers in September 2008, sparked a global financial crisis that affected the real sector and caused a rapid, synchronized deterioration in most major economies. From August 2007 onwards, yield spreads of Euro area government bonds with respect to Germany spiraled in parallel with the rise in global financial instability that led to «flight-to-quality», resulting in a

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transfer of funds towards assets with a lower risk (German bunds) and an increase of the risk premium in the other EMU countries. Therefore, in few years the EMU sovereign bond markets went from a situation of high stability to their current situation of turmoil connected to the most recent sovereign debt crisis in the Euro area. Contemporaneously, Euro area stock markets have jointly experienced an increase of turbulence, by raising concerns regarding the level of financial systemic risk.

The speed of these phenomena and their geographical reaches, are difficult to explain by only pointing to «fundamentals». «Contagion» became the catchword for such processes and it is now widely being used to describe the events around the Lehman's default crisis and the sovereign debt crisis which led to the rescues of Greece, Portugal, and Ireland in 2010/2011. Do these periods of highly correlated market movements provide evidence of contagion? Before answering this question, it is necessary to define contagion. Notwithstanding that there is widespread disagreement about what this term entails, a vast body of empirical literature follows Forbes and Rigobon (2002) definition of contagion as «a significant increase of cross-market linkages after a shock to one country (or group of countries)». Markets that were assumed to be weakly associated before a shock are subsequently found to be strongly associated, so that diversification across markets fails to shield the investor from unsystematic risk.

Without a clear understanding of financial contagion and the mechanisms through which it works we can neither seriously assess its importance nor design appropriate policy measures. The policy implications associated with fundamentals-driven and contagion-driven movements are quite different. In the first case, policymakers cannot expect the markets to recover unless measures are taken to improve fundamentals. On the other hand, if markets are declining owing to contagion, then credible policy actions to improve market sentiments ought to be a priority.

The aim of our empirical study is to identify if there has been contagion during the Lehman and sovereign debt crises. Moreover, we try to define an approximate periodization for contagion effects by looking directly into the data, that is, without making *a priori* conjecture on the time periods during which the contagion process could have started to spread out. We contemporaneously take into consideration two crises (Lehman and sovereign debt crises) and two assets (sovereign bonds and stocks).

Our study adopts a comprehensive approach to get some insights on different patterns of contagion transmission across EU countries, by applying Granger causality/Vector error correction models (VECM). The use of this methodology allows us to identify contagion, by testing for the presence of new significant links among countries after financial shocks, and to establish which are the countries that propagate the impulses of contagion (*leading countries*) and which are the countries that are, instead, the target of contagion (*follower countries*). Lastly, we identify the most vulnerable countries by building a «rate of involvement indicator», that measures how much «domestic» risk is explained by innovations in foreign countries.

Our results reveal the fact that causality patterns change in the crisis period compared to the tranquil one; this result suggests evidence that contagion effects have strongly influenced asset price dynamic over the two recent crisis episodes. Moreover, we find that empirical results in terms of both contagion periodization and contagion mapping (identification of leading and follower countries) are different for the stock market with respect to the sovereign bond one. Lastly, we provide valuable evidence on the changes in the patterns of the contagion propagation phenomenon among Euro area countries.

The remainder of the paper is organized as follows. Section 2 shortly reviews the literature on contagion. Section 3 describes the data and the methodology. Results are discussed in Section 4 and Section 5 concludes.

2 Review of the Literature

2.1 Definitions of Financial Contagion

Contagion, in general, is used to refer to the spread of market disturbances – mostly on the downside – from one country to others, a process observed through co-movements in exchange rates, stock prices, sovereign spreads and capital flows. Contagion can occur for different reasons and can conceptually be divided into several categories. Therefore the first challenge comes from the definition of contagion. In spite of significant theoretical and empirical interest in the topic, indeed, there is still no consensus on either the definition or the transmission channels of financial contagion. We can distinguish at least three different definitions of financial contagions, though the first one is just a vague and general one used in the early stage of the research in this topic.

Under such an early stage approach, contagion is viewed as any cross-country transmission of shocks or any general cross-country spillover effects during the crisis. Contagion can be observed through co-movements of different asset prices in different countries or rising probabilities of default if the crisis occurs elsewhere. Unlike the following and more precise definitions, this one includes any type of linkages as a channel of contagion (i.e. both fundamental and non-fundamental; Gerlach and Smets, 1995; Drazen, 1998). The theories based on fundamental channels are the oldest and the general idea is that links across countries exist because the countries' economic fundamentals affects one another. These theories are usually based on standard transmission mechanisms, such as trade, monetary policy, and common shocks (eg.: oil prices).

In the second and more focused definition in the recent literature, contagion is defined as the transmission of shocks from one country to others or the cross-country correlation, beyond what would be explained by fundamentals or common shocks[1]. For example, Masson (2004) defines contagion as meaning only «those transmissions of crises that cannot be identified with observed changes in macroeconomic fundamentals». Using a different terminology, Eichengreen *et al.* (1996a) argue that there is contagion if the probability of a crisis in a given country increases conditionally on the occurrence of a crisis elsewhere, after controlling for the standard set of macroeconomic fundamentals. This definition is sometimes referred as excess co-movement – a correlation that remains even after controlling for fundamentals and common shocks.

[1] Fundamentals causes of contagion include macroeconomic shocks that have repercussions on a international scale and local shocks transmitted through trade links, competitive devaluations, and financial links.

In the third definition, contagion occurs when cross-country correlations increase during «crisis times» relative to correlations during «tranquil times»: this can only be due to factors unrelated to fundamentals, since fundamentals cannot change in a short period of time. In particular, Forbes and Rigobon (2002) argue that «contagion is a significant increase in cross-market co-movements after a shock». In our study we follow this definition of contagion which does not require the specification of a structural representation for sovereign spreads and stock returns. The identification of a fundamentals model, can be cumbersome with the risk of inflating the «contagion proxy», could be quite high, because of omitted variable problems. According to this definition, if two markets show a high degree of co-movement during periods of stability, even if the markets continue to be highly correlated after a shock to one market, this may not constitute contagion. There is *contagion* only if cross-market co-movements increase significantly after the shock. Any continued high level of market correlation suggests strong linkages between the two economies that exist in all states of the world. This definition implies that contagion effects are to be differentiated from «normal» transmissions of shocks across countries, usually defined as interdependencies. Indeed, Edwards (2000) asserts that contagion reflects a «situation where the effect of an external shock is larger than what was expected by experts and analysts», which implies that contagion has to be differentiated from the «normal» transmission of shocks across countries.

2.2 Empirical Literature

Forbes and Rigobon (2002) have suggested discriminating empirically between contagion and interdependencies by testing whether cross-market correlation significantly increases during time periods of instability. They argue that simple correlations are biased due to the presence of heteroskedasticity, endogeneity, and omitted variables[2]. After correcting for these statistical problems for the cases of the 1994 Mexican crises, the 1997 Asian Crises, and the 1987 US stock market crash, the authors conclude to have found «only interdependencies, no (pure) contagion»[3].

Andenmatten and Brill (2011) also perform a bivariate test for contagion that is based on the approach proposed by Forbes and Rigobon (2002) to examine whether the co-movement of sovereign CDS premium increased significantly after the beginning of the Greek debt crisis in October 2009. They conclude that in European countries «both contagion and interdependence occurred».

Gómez-Puig and Sosvilla-Rivero (2011) provide empirical evidence of the existence of sub-periods of contagion phenomenon during different periods since 1999 for EMU

[2] During times of increased volatility (i.e. in times of crisis) estimates of correlation coefficients are biased upward. If co-movement tests are not adjusted for that bias, contagion is too easily detected.

[3] They proposed an adjusted correlation coefficient which takes into account the changing market volatility. Recently, Corsetti *et al.* (2005) have contested this view by questioning the Forbes-Rigobon methodology. They show for the case of the Hong Kong stock market crisis of October 1997 that this conclusion cannot be empirically generalized.

countries – they measure co-movements in terms of links among countries by applying the Granger causality test. They identify contagion episodes as «sub-periods of significant increase in causality». Their results suggest that contagion episodes are concentrated around the first year of EMU in 1999, the introduction of euro coins and banknotes in 2002, and the global financial crisis in the late-2000s. Moreover, they also indicate that causality relationships between peripheral EMU yields have risen significantly during the recent crises in sovereign debt markets from 2009, providing evidence of an increase in the contagion between them.

Kalbaska and Gatkowski (2012) analyze the Granger causality dynamics of the CDS market of PIIGS, France, Germany, and the UK for the period of 2005-2010 aiming to examine sovereign risk and the occurrence of financial contagion in Europe. The Granger causality test revealed that cross-country connections increased after the global financial crises as compared to the pre-crisis period. Results also highlighted that Greece and other PIIGS have lower capacity to trigger contagion than core EU countries. Moreover, Portugal is the most vulnerable country, whereas the UK is the most immune one to contagion.

The empirical literature based on stock returns uses several methodologies to measure how contagion is transmitted internationally. We will focus on the major contributions based on cointegration (VECM)/Granger causality test analysis. Several studies have adopted the cointegration model as a measure of co-movement between countries in order to specifically measure the impact of crises on stock market trading activity. Malliaris and Urrutia (1992) have demonstrated that cointegration among stock markets has drastically increased during the October 1987 crisis, assuming that an increase of the number of cointegrated markets du-ring crises periods relative to tranquil ones constitutes evidence for contagion. Yang, Kolari and Min (2003) have examined both long-run and short-run relations among the US, Japanese and ten Asian stock markets during the 1997-1998 Asian financial crisis and find that long-run cointegration relations among these markets were strengthened during the crisis and that these markets have been more integrated after the crisis than before. Also Arshanapalli *et al.* (1995) provide evidence of the presence of a common stochastic trend between the US and Asian stock market movements post October 1987. Lastly, Sheng and Tu (2000) apply a multivariate cointegration model to measure the effects of the Asian financial crisis among 12-Asia Pacific countries and find that during the crisis new long-run relations among stock markets emerged and that contagion effects were stronger in the South-East Asian countries compared to the North-East Asian countries.

Serwa and Bohl (2005) use instead the same approach as Forbes and Rigobon (2002) – based on the adjusted correlation coefficient – in examining the co-movements of stock returns by cross-market correlation. They find that Central European stock markets are no more likely to be subject to contagion than western stock markets over the 1997-2002 period and conclude that the Central European stock markets exhibit *interdependence* rather than *contagion*.

2.3 Economic Explanations of Contagion

There are several economic theories which could explain cross-countries propagation of shocks. Theoretical models, which could be beyond contagion processes, are based on completely different hypotheses.

First of all, information imperfections and costs of acquiring and processing information make a correct assessment of fundamentals complex and a certain degree of lack of knowledge rational. As a result, market participants are uncertain about the true state of a country's fundamentals. A crisis elsewhere might lead them to reassess the fundamentals of other countries and cause them to sell assets, to call in loans, or to stop lending to these countries, even if their fundamentals remain objectively unchanged. Goldstein (1998) affirms that a crisis in one country may serve as a «wake-up call» for market participants if it causes them to take a closer look at fundamentals similar to those in the country affected by the crisis. Contagion occurs if this leads them to detect problems or risks they failed to see before.

Another line of argument takes a crowd psychology approach and employs a form of «mental contagion» in the tradition of the classical financial panic view, depicting financial crises as self-fulfilling expectations phenomena or coordination failures among agents in the presence of multiple equilibria. Contagion arises if a crisis elsewhere serves as the «sunspot variable» that leads agents to co-ordinate their expectations on crisis equilibria. The most straightforward version is the one of «cascading defaults» and is a matter of ordinary credit risk (Marshall, 1998). High exposure to troubled private or sovereign debtors may lead to cross-border transmission of failures if losses for creditors are large enough. This is particularly likely if banks are among the major creditors, as they operate with relatively low capital-to-asset ratios.

A number of authors have pointed out that liquidity or capital constraints could impose greater than optimal asset reduction on international investors affected by a crisis in one market, forcing them to unwind positions in other markets to raise liquidity. This unwinding could occur if investors need to meet margin calls or other collateral requirements, or fulfill investor redemptions in the case of mutual funds. As originally suggested by Valdés (1997), liquidity needs could also arise if market liquidity sharply declines or virtually dries up because a market maker or important market participant suffers large losses and withdraws funds, or if several participants unwind similar positions at the same time.

Capital constraints are another factor that could impose greater than optimal asset reduction on investors affected by a crisis. Particularly, capital requirements that induce banks to adjust their capital ratios might cause them to cut back foreign loans or, in the case of ratios to risk-weighted assets, shift into low-risk assets such as government securities. A bank could also respond by improving the numerator in the capital–asset ratio, perhaps by issuing equity or by retaining earnings, although this might be difficult in times of crisis.

3 Methodology

The methodology that we are going to apply is coherent with our definition of contagion as a significant increase of the total number of cross-market connections around the two shocks (Lehman default and sovereign debt crises). So in order to test for contagion, we have to identify «crisis» and «tranquil» periods of time.

In the financial literature, evidence has been frequently provided in recent years indicating that during crisis, new co-integration relationships among markets appear, which were not observed during tranquil periods of time. These new long-run links generally involve countries which have a relevant role in the spreading out of contagion (Arshanapalli *et al.* (1995); Malliaris and Urrutia (1992); Sheng and Tu (2000); Jang and Sul (2002); Yang *et al.* (2003); Sander and Kleimeier (2003); Click and Plummer (2005)). As a consequence, we use bivariate dynamic cointegration analysis to test for the presence of new long-run equilibrium conditions among countries through the application of dynamic rolling cointegration analysis for each pair of countries. In this way we identify contagion windows, given that the use of the simple correlation indicator seems to fail in the identification of instability periods of time (see Appendix).

Subsequently, through the Granger causality test we evaluate, in the contagion windows identified in the previous step, changes of the short-run connections among countries. Moreover, the Granger causality methodology allows us to detect the *direction* of these connections and, consequently, to examine how shocks are transmitted across countries. An increase of Granger-causality connections is a signal of a contagion occurrence. Alongside the above short-run *direction* of the links, we are interested in detecting the log-run *direction* of the countries' connections and to this end, we implement the Gonzalo-Granger statistic.

Finally, we apply the *variance decomposition* (see the Appendix) method to test for a reduction in the degree of exogeneity of a particular country. Indeed, if a country is less exogenous to the system, it is more exposed to the eventual transmission of shocks and, as a consequence, it is more vulnerable if there is contagion.

In sum, comparing all test results (for the stock and sovereign debt markets) in «tranquil» versus «crisis» periods, we present evidence of contagion across EU countries over the period encompassing the two last recent financial crises (Lehman default and sovereign-debt crisis).

4 Results

Our sample is composed of eight European countries: France, Germany, Greece, Ireland, Italy, Portugal, Spain, and United Kingdom. We test for co-movements across countries using two type of assets (equities and sovereign bonds). In regard to sovereign bonds, we use the sovereign spreads time series computed as the difference between the selected countries sovereign bond yields and the corresponding US-Treasury yield[4], which is a proxy of country-specific credit risk, and therefore, can be interpreted as an

[4] We compute spreads by using US Treasury as benchmark, by following the approach frequently applied in the literature. Moreover, in this way we maintain a high level of symmetry between equity and sovereign bond applications, given that the US is included also in the stock return model. If we used German bonds as a benchmark, we would have to leave out this country from the analysis.

indicator of the effects of the crisis as perceived by the international market (Sander and Kleimeier, 2003)[5].

Regarding the stock market, we use daily stock index closing prices. We consider data at the daily frequency, because interdependence phenomena can explode also in few days, so if we consider weekly or monthly data we can lose the measurement of interactions which last only a few days. All data (sovereign bond spreads and stock index prices) are retrieved from the Datastream database, and the time span of our time series goes from the first of January 2003 to the 30th of September 2012.

4.1 Identification of Contagion Windows

Our analysis begins, as already mentioned in the methodology section, by examining how the number of connections among Euro area markets has evolved through time. In other terms, at each point of time we estimate the number of markets interrelated in the sense that they are able to influence each other in the determination of sovereign bond spreads and stock returns; a sharp increase in the number of cross-market connections signals a contagion phenomenon. According to the results obtained in this step, we detect contagion windows by looking directly into the data, finding evidence which either confirms or rejects our *a priori* conjectures on the occurrence of shocks, and on the periods during which contagion may have started to spread out during the two financial crises analyzed. In particular, we apply a dynamic bivariate cointegration analysis detecting long-run relationships, which are connections among markets that lead to slow price adjustment processes. We take into consideration daily changes of sovereign spreads and stock index returns, because we have verified that sovereign spread and log-price are not stationary in levels. To detect possible contagion periods, we dynamically apply the Johansen cointegration test between all the possible couples of countries[6] with a rolling window of 1,000 days[7], by computing at each step t of the procedure the following rolling indicator of cross-country connections:

$$\textit{Percentage of cross-country connections}_t = \frac{\textit{Number of long-run relations}_t}{\textit{Maximum number of long-run relations among all countries}} * 100.$$

We identify as contagion windows those periods of time recording the values of *cross-country connections* above the 75th percentile of the distribution. On the contrary, we identify as tranquil periods those reaching a *cross-country connections* value beneath the 25th percentile of the distribution. The use of quantiles to identify significant increases of

[5] We have chosen bonds that are similar across countries according to their maturity. For the sake of results comparability, we selected bonds with a 10 years maturity for all countries over the whole sample period. Bond yield spreads incorporate also liquidity effects. We have not used sovereign CDS time series, because this market is relatively new and liquid sovereign CDS data are only available since November 2008. Also taken into consideration is that CDS data does not allow us to analyze the effects of Lehman default crisis.

[6] As already mentioned, our sample comprises eight European countries, therefore we have 28 total couple combinations.

[7] The use of the 1,000 day-window makes our co-integration results more robust, because it allows us to exploit the asymptotic properties of the Johansen co-integration test, as shown by other empirical applications in which the same window size has been applied (see for reference Arce *et al.*, 2012).

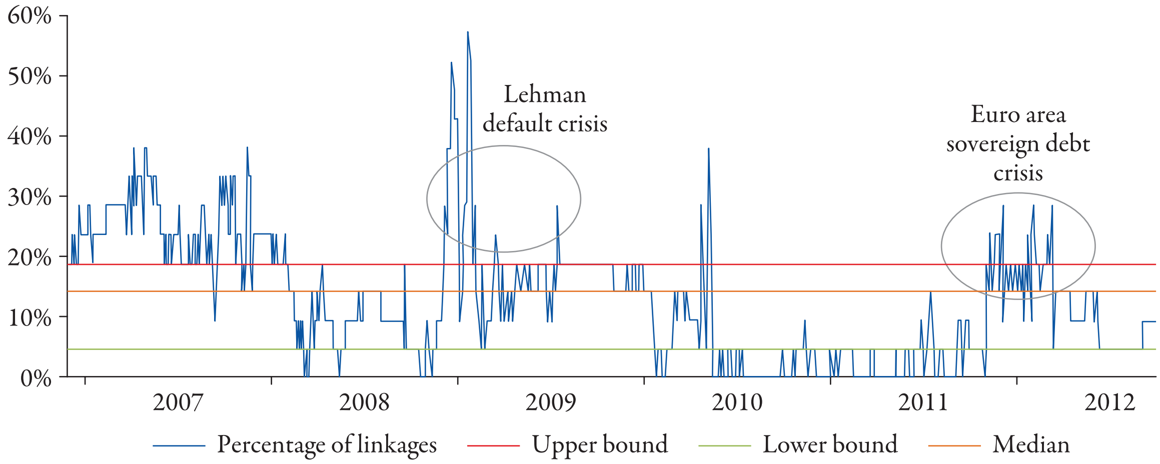

Figure 1: Contagion windows estimation using sovereign spreads.

asset price co-movements is justified on the basis of recent developments of econometric techniques which apply quantile smoothing splines (Koenker *et al.*, 1994; Koenker, 2005) to identify «abnormal» asset prices movements during crises[8].

In Figure 1, we plot the mentioned indicator and its bounds applying the just described methodology to sovereign spreads. The indicator has been quite stable above the III° quartile for most of the period from October 2006 to around December 2007, but we do not detect a significant change in the number of connections, and hence we take this evidence as a sign of *interdependence* rather than *contagion*.

The first contagion window using sovereign spreads corresponds to the Lehman default crisis and spans, instead, from December 2008 to July 2009. In fact, during this period, which lasts 162 days, in 24% of the cases the indicator of the percentage of connections is above the III° quartile, and in 81% of the cases it is above or equal to the median. In the previous «tranquil» window, which goes from April 2008 to November 2008, the indicator is stably low, given that in 73% of the cases it is strictly under the median and in 36% of the cases it is under the lower bound.

The second contagion window corresponds to the sovereign debt crisis and spans from November 2011 to May 2012. During this period of time, which lasts 155 days, in 79% of the cases the indicator is above or equal to the median and, in particular, in 14% of the cases the indicator is strictly above the upper bound. The related benchmark «tranquil» period of time spans from May 2010 to December 2010 when the indicator is always under the median. As a consequence, also in this case the indicator increases sharply during the crisis episode.

In a similar way we identify contagion windows using stock returns, though in this case the lower bound is equal to zero (Fig. 2). Using equity returns we detect two contagion windows. The first one – which covers the Lehman default crisis – spans from March 2008 to July 2009 and lasts 354 days (when in 88% of the cases the indicator of connections is above or equal to the median and, in particular, in 54% of the cases it is strictly above the upper bound), while the benchmark «tranquil» period goes

[8] See Caporin *et al.* (2012) as a reference for an empirical application of quantile regressions to detect contagion.

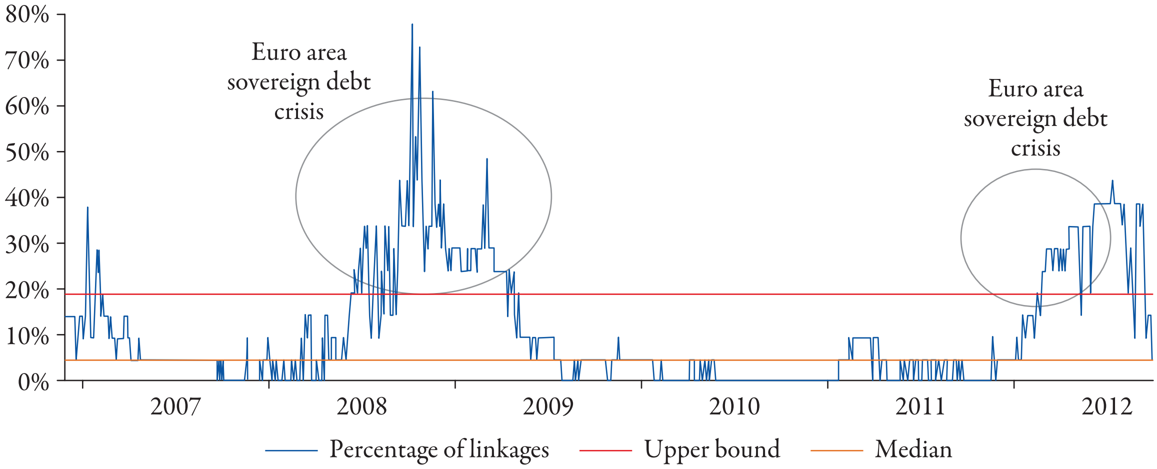

Figure 2: Contagion windows estimation using stock returns.

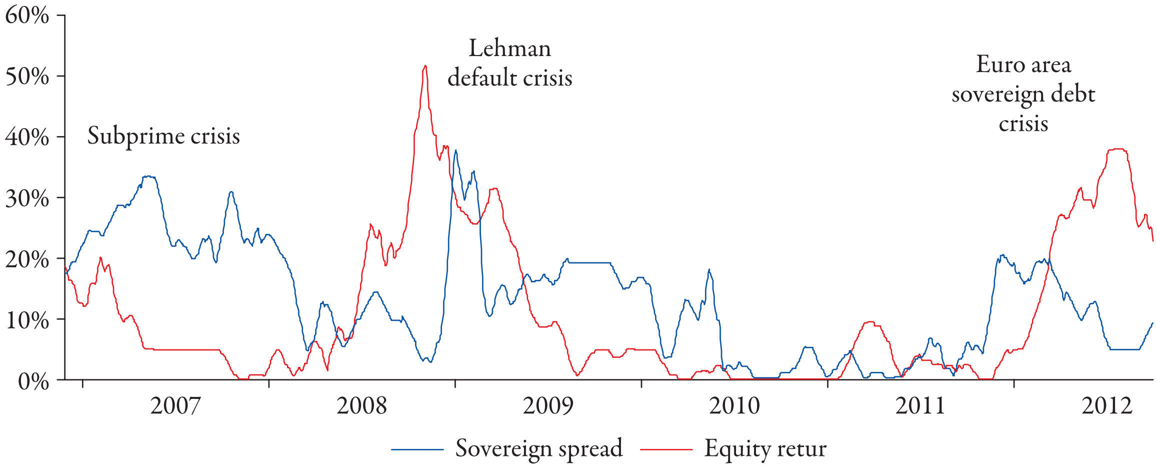

Figure 3: Comparing contagion windows using sovereign spreads and stock returns.

Note: In the graph we represent the moving average of the percentage of significant connections computed by applying a window of 20 days. In the computation of the indicator we consider all the significant long-run connections among the Euro Area countries included in the sample.

from October 2006 to February 2008 (when the indicator is low, given that it is most always below the median). The second contagion window covers the sovereign debt crisis period and spans from January 2012 to September 2012. In this case, the indicator is always above or equal to the median (and, in particular, in 67% of the cases the indicator is strictly above the III° quartile). The «tranquil» period goes instead from June 2010 to January 2011, when the indicator of the percentage of significant connections is always equal to zero.

In Figure 3 we represent the indicator (the percentage of significant cross-market connections on the total amount of possible relations) for both sovereign spreads and stock returns, in order to highlight the differences in the pattern of crisis dissemination. From October 2006 to October 2007 the percentage of significant cross-market sovereign spread connections remains at quite high levels pointing out a situation of possible *interdependence* instead of contagion. Indeed, if co-movements do not significantly grow,

Table 1: Characteristics of the contagion windows

	Lehman default crisis	Euro area sovereign debt crisis
Sovereign spreads	01/12/2008-14/07/2009; 162 days; in 84% of the cases the indicator is above or equal to the median; in 24% of the cases the indicator is strictly above the upper bound.	02/11/2011-05/06/2012; 155 days; in 79% of the cases the indicator is above or equal to the median; in 14% of the cases the indicator is strictly above the upper bound.
Stock returns	10/03/2008-16/07/2009; 354 days; in 88% of the cases the indicator is above or equal the median; in 52% of the cases the indicator is strictly above the upper bound.	09/01/2012-28/09/2012; 190 days; in 100% of the cases the indicator is above or equal to the median; in 67% of the cases the indicator is strictly above the upper bound.

then any continued high level of market correlation suggests strong connections that exist in all states of the world, that is a situation of *interdependence*.

The sovereign spreads contagion indicator reaches a peak at the end of 2008, that is with some delay with respect to the Lehman default. In this case, over 30% of all the possible cross-market relations are significant with a sharp increase compared to the levels observed in the period immediately before (less than 10%). Thereafter, the indicator is quite volatile until May 2010 when European central Authorities fixed the first set of financial aids for peripheral Euro area countries. Then, the percentage of connections among sovereign spreads remains at a quite low level. At the end of 2011, the indicator reaches a new peak, which is, however, lower compared to the one observed during the Lehman default crisis. The indicator of the intensity of cross-market connections shows a different pattern on the stock return time series; in this case we clearly identify two contagion episodes. The first one starts in approximately March 2008 and ends around July 2009 and includes, consequently, both the subprime and the Lehman default crisis; in September 2008 more than 50% of the cross-market relations are significant. The second peak is reached during the sovereign debt crisis in 2012, when, however, the percentage of cross-market relations did not overcome 40%.

When comparing the timing of contagion for the two assets (sovereign spreads and stock returns), we notice that during the Lehman crisis the increase of co-movements in the stock markets anticipates the raise of correlation among Euro area sovereign spreads, while during the sovereign debt crisis bond spreads contagion led the increase of correlation among stock markets. It is possible to conjecture that during the Lehman crisis the increase of co-movements in stock markets anticipates the raise of correlation among Euro area sovereign spreads mainly because of the intrinsic financial nature of the first crisis. The Lehman crisis stems from financial shocks and it is quite natural that it shows its first effects in terms of contagion in the stock market. The sovereign debt crisis, instead, stems from macroeconomic factors and it is not counterintuitive in that it shows its first contagion effects in the sovereign bond market.

In Table 1 we summarize the results on the contagion windows, which will be used in the next section in order to analyze the contagion process and to verify if the number of significant connections in the «crisis» period grows compared to the «tranquil» period. Indeed, until now we have only considered long-run connections which imply a slow price adjustment process. However, to verify the presence of contagion we have to compute the total number of connections, not only the long-run ones, but also the short-run connections on the basis of the Granger causality test.

4.2 Analysis of the Contagion Process

In this section we compare the number of significant cross-market connections which emerged during the mentioned «crisis» episodes with the amount of cross-market relations in «tranquil» periods. In particular, we study the patterns of the contagion process by applying the Granger causality test on the basis of multivariate VECM models (see the Appendix for details). The co-integration test allows us to identify connections between couples of markets which lead to slow price adjustment processes (*long-run connections*). Not only do we detect links, but we also find the direction of each significant connection by applying the Gonzalo-Granger statistic. The Granger causality test, instead, identifies connections which have a short-term influence in the price discovery process (*short-run connections*).

As a result, both techniques (the cointegration test/Gonzalo Granger statistic and Granger causality test), allow us to identify significant cross-market connections and the direction of these relations. Thereafter, by applying the two tests we can establish which countries have a dominant role in the contagion process, because they are able to influence the others («leading countries»), and which countries are more vulnerable in the sense that they are more reactive to other countries' price innovations («follower countries»). The only difference is the time horizon of the price adjustment process induced by the existence of cross-market connections, which is the long-run for the connections identified by the Johansen cointegration test, while it is the short-run for the connections detected with the Granger causality test. In Figure 4, we represent all the relations (short-run and long-run) among sovereign spread markets and the direction of these connections which shed light on the structure of the contagion propagation mechanism; only when a link is statistically relevant do we report the value of the test statistic and its significance level (see also Tab. A.1 in the Appendix).

During the recent sovereign debt crisis, there has been an increase of the significant connections among sovereign spread markets, which has grown from 8 (May 2010-December 2010) to 13 (November 2011-May 2012). The representation that we have chosen allows us to go through the structure of the contagion transmission mechanism. During the sovereign debt crisis (November 2011-May 2012), Germany and Spain have a dominant role in the contagion process, because they are able to influence most of the other countries. Indeed, Germany, which was connected only with Portugal during the Lehman crisis (December 2008-July 2009), has influenced Italy, Spain, and Ireland during the more recent sovereign debt crisis (November 2011-May 2012). Spain which did not lead any country in 2008-2009 (Lehman default crisis) has started to influence Greece, France, and Portugal since the end of 2011. The number of cross-market connections has, instead, decreased, with respect to the Lehman default crisis (December 2008-July 2009), from 5 to 4 for Portugal, and from 5 to 2 for Greece. Moreover, Portugal and Ireland, which dominated the contagion process during the Lehman default crisis, have clearly

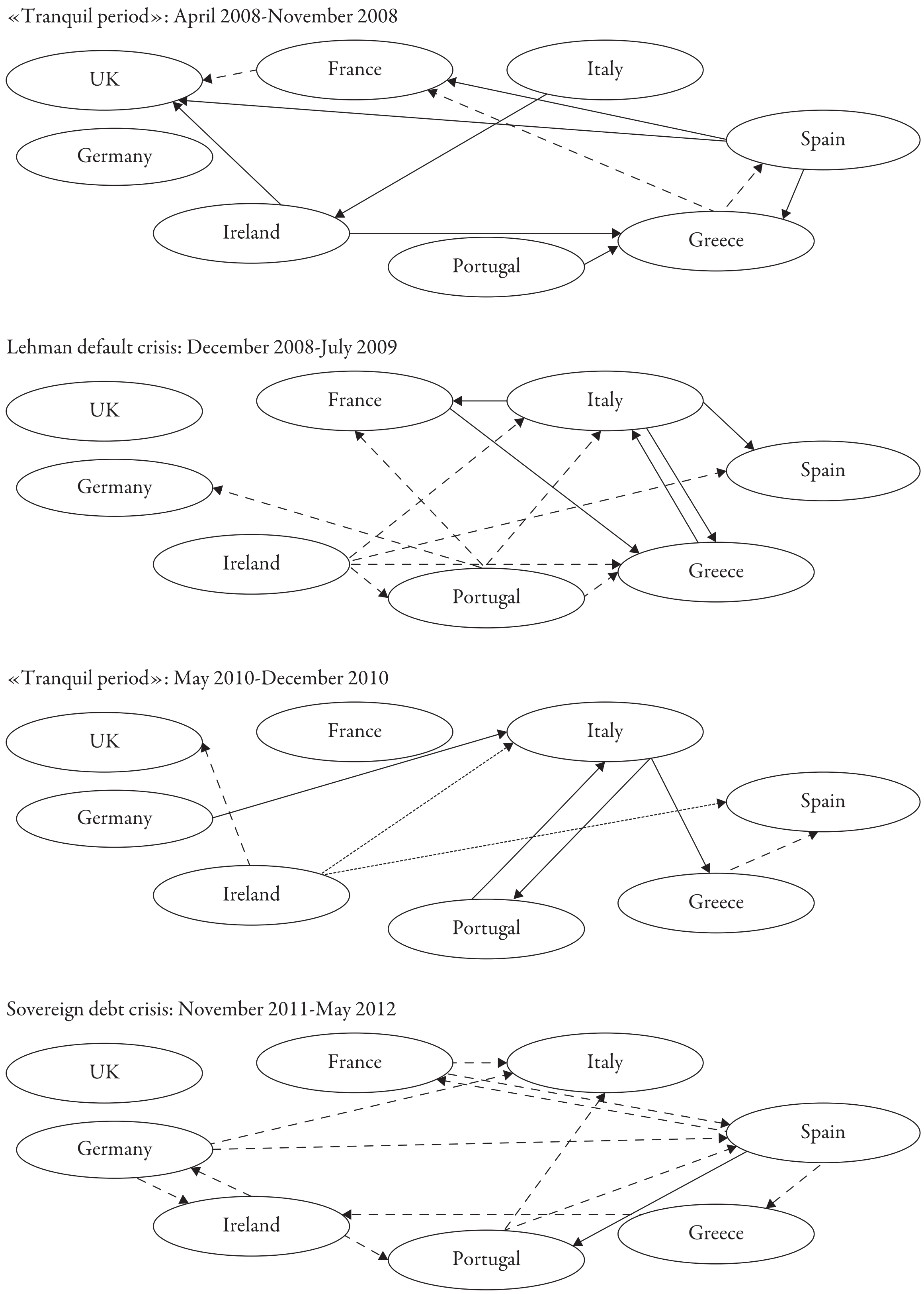

Figure 4: Contagion tests using sovereign spreads: short and long-run connections before and after crises episodes.

Note: we use a dashed line in the case of short-run connections, a solid line refers to the long-run connections, and the bold line is used when both short and long-run connections are detected.

lost their leading role in 2011-2012. Lastly, Italy became a pure follower country in the sense that it absorbed shocks without being able to influence other countries signaling a high degree of vulnerability.

The procedure applied on stock returns is analogous to the one just described for sovereign spread time series. In Figure 5 we represent all the relations (short and long-run) using stock returns and the direction of these connections to shed light on the structure of the contagion propagation mechanism; when the connection is statistically relevant we report the value of the test statistic and its significance level (Table A.2 in the Appendix).

During the sovereign debt crisis, the number of cross-market connections sharply increases, growing from 4 (June 2010-January 2011) to 17 (January 2012-September 2012). However, results differ when taking into consideration the direction of the connections, compared to sovereign spreads. In particular, Germany, France, and Greece, which dominated the stock market during the Lehman default crisis as leading countries (March 2008-July 2009), clearly lose this role during the sovereign debt crisis (January 2012-September 2012). Indeed, in 2008-2009, Germany was able to influence the stock returns of all the other countries except for Ireland, while during the sovereign debt crisis it has not led any country and it has been significantly connected only with Italy and the UK. In 2008-2009, France had a dominant role in the contagion transmission mechanism by influencing Germany, Italy (both short and long-run), Spain and Portugal, while in the more recent sovereign debt crisis France led only Portugal and Ireland. Moreover, Italy, which during the Lehman default crisis did not influence any countries and was connected only with Germany and France (March 2008-July 2009), in the more recent crisis has been significantly connected with Spain, Greece, Portugal, and Ireland (January 2012-September 2012). Lastly, during the sovereign debt crisis, Italy, Greece, and the UK have had a dominant role in the contagion transmission mechanism and the number of relevant connections which involve Portugal and Ireland has been higher compared to what was observed in 2008-2009.

As a result, the evidence of contagion using stock returns has quite a different pattern compared to the one observed for sovereign spreads. In the case of stock returns, indeed, the risk profile of Italy becomes closer to the risk profile of Spain, Greece, Portugal, and Ireland, given that the number of connections among these countries grows significantly. Moreover, the contagion process is mainly related to peripheral countries rather than to core ones. One important feature of our results which confirms the existence of *contagion* as opposed to *interdependence* is that the number of connections detected among countries (in either sovereign bond or stock markets) increases after the «crisis episodes» but do not stabilize at such higher levels reached after the shock. Indeed, the number of connections goes up during «crisis periods» and then comes back down during «tranquil periods». As said in §2.1, such features are a critical test to distinguish between *contagion* and *interdependence*, since contagion is a significant increase in the comovement between assets during a period of crisis, compared with a tranquil period. Therefore, if there is a high level of market comovement in all periods, then it is the case of *interdependence*. As regards to the European countries analyzed in our paper, a higher number of connections which don't hold steady after a shock – but return to low values once the crises is

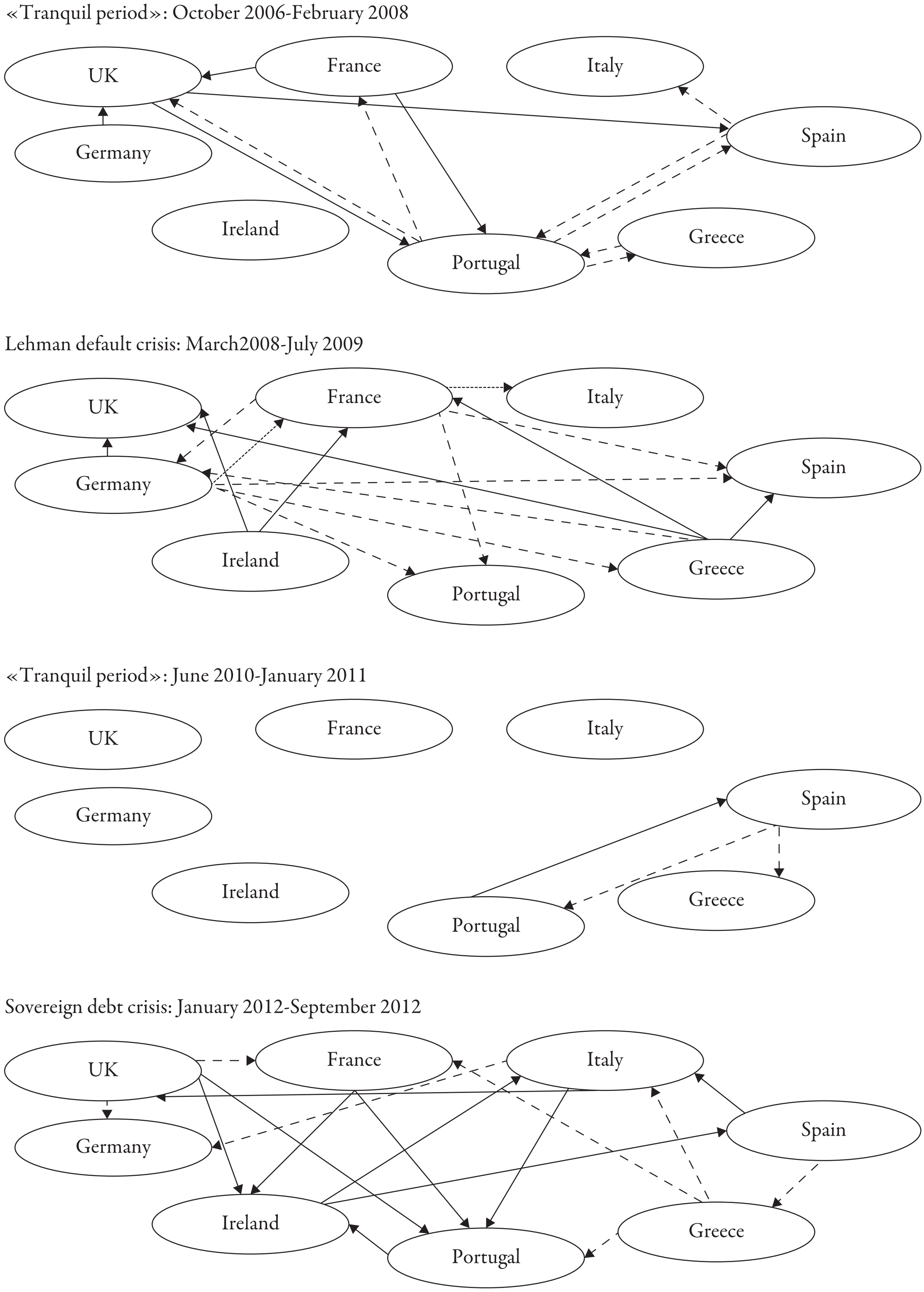

Figure 5: Contagion tests using stock returns: short and long-run connections before and after crises episodes.

Note: We use a dashed line in the case of short-run connections, a solid line refers to the long-run connections, and the bold line is used when both short and long-run connections are detected.

Table 2: Rate of involvement in the contagion process using sovereign spreads (%)

	«Tranquil» period before Lehman default	Lehman default crisis	«Tranquil» period before sovereign debt crisis	Sovereign debt crisis
Germany	6.42	2.87	4.42	7.94
France	3.60	4.91	2.06	2.93
Italy	2.55	6.95	7.20	8.33
Spain	3.76	3.92	6.89	16.13
Greece	2.24	10.01	4.77	6.79
Portugal	4.15	8.45	3.40	3.71
Ireland	6.61	10.66	2.62	5.37
UK	5.94	8.92	8.01	7.89

Note: The variance-decomposition has been computed on 5 days forecast horizon.

gone – is a signal of a temporary distortion of the transmission channels due to shocks (that is *contagion*), instead of a systematic change in the common economic structure (owing to real or financial links).

4.3 Rate of Involvement in the Contagion Process

Our last step relates to the application of the variance decomposition methodology which is an aggregate measure of each country's degree of exposition to the influence of foreign markets and, as a result, indicates the rate of involvement in the contagion process (see the Appendix). As regards to sovereign spreads and on the basis of this indicator, Germany and Spain are more significantly involved in the sovereign debt crisis compared to their involvement in the Lehman default one (Table 2). Indeed, between the two crises the ratio of the forecast error variance explained by foreign markets has increased from 3% to 8% for Germany, and from 4 to 16% for Spain. Italy has been highly involved in the recent contagion process given that its degree of exposition to external shocks is the highest in the sample after Spain. This level of exposition to external shocks together with the fact that Italy has been found to be uniquely a follower country can be considered as a signal of its high degree of vulnerability. Looking at the differences between the rates of involvement before and after the two crises considered, we can get some insight on contagion intensity for the countries in our sample: Spain, Germany, and Ireland are countries mostly involved by the contagion process during the sovereign debt crises, which means that their degree of exposition increased after the crisis more than those of other countries, although Spain and Italy are the countries that record the highest level of vulnerability (respectively 16% and 8%)[9]. As regards to the Lehman default crisis, Greece, Italy, and Portugal are countries that record the most severe worsening of external fragility, in contrast to Germany, which was essentially unaffected[10].

[9] For example, the rate of involvement for Germany moved from 4.42% to 7.94% after the sovereign debt crises, reaching an increase of about 3.52% which was the highest in the sample except for Spain (from 6.89% to 16.13%), although the highest levels of exposition after the crises are those of Spain and Italy (16.13% and 8.33%).

[10] The rate of involvement for Italy goes from 2.55% to 6.65%. Greece moves from 2.24% to 10.01%, and Portugal from 4.15% to 8.45%.

Table 3: Rate of involvement in contagion process using stock returns (%)

	«Tranquil» period before Lehman default	Lehman default crisis	«Tranquil» period before sovereign debt crisis	Sovereign debt crisis
Germany	2.86	2.81	1.72	4.08
France	3.25	7.35	1.95	2.04
Italy	3.92	7.98	6.19	6.25
Spain	3.68	8.82	7.44	6.88
Greece	1.47	3.89	2.57	4.07
Portugal	4.48	6.72	11.24	11.95
Ireland	2.03	2.90	1.18	2.81
UK	4.04	5.08	2.23	5.29

Note: The variance-decomposition has been computed on a 5 day forecast horizon.

Using stock returns, the most involved countries in both crisis episodes are Portugal, Spain, and Italy (Table 3). Moreover, the rate of involvement of Portugal in the sovereign debt crisis increased significantly compared to what was observed during the Lehman default crisis, given that the ratio of the forecast error variance explained by foreign market innovations increased from 7 to 12%. The degree of exposition of France has, instead, decreased from 7 to 2%. Therefore, even using this methodology, the role of peripheral countries in the contagion process during the sovereign debt crisis has been more relevant compared to «core» countries. It is interesting to note that Italy and Spain have almost the same rate of involvement in the sovereign debt crisis (respectively 6.25% and 6.88%). As regard to the Lehman default crisis, Spain and Italy are the two countries most affected both in terms of degree of exposition to external markets (8.82% for Spain and 7.98% for Italy) and in terms of the growth rate of vulnerability before and after the crises (from 3.68% to 8.82% for Spain and from 3.92% to 7.98% for Italy). Looking at the more recent sovereign debt crises, results highlight that Portugal, Spain, and Italy are the countries more exposed to financial contagion due to them having the highest degrees of fragility (about 12%, 7% and 6%), while Germany and Ireland record the lowest performance in terms of rise in rate of involvement due to their very low pre-crisis vulnerability (from 1.72% to 4.08% for Germany, and from 1.18% to 2.81% for Ireland).

5 Synthesis of the Results

In Table 4 we summarize the main results obtained in sections 4.1, 4.2. and 4.3 regarding both sovereign spreads and stock returns. When using sovereign spreads, Germany and Spain have a leading role in the contagion process and are the most involved countries in the sovereign debt crisis episode; Italy, instead, is a follower country, in the sense that it is not able to influence other countries in the spread innovation process, showing, consequently, a high degree of vulnerability. When using stock returns, instead, Germany and France have a minor role in the contagion transmission mechanism during the sovereign debt crisis. The Italian stock market is more closely connected with peripheral countries compared to the «core» ones. There is a sharp increase of the

Table 4: Evolution of cross-market connections

Crisis	Presence of contagion	Direction of contagion	Rate of involvement in the contagion process
Sovereign spreads			
2008-2009 – Lehman default crisis	The number of connections has increased respect the benchmark «tranquil» period of time: there has been a contagion process	Italy, Portugal and Ireland have a leading role in the process of transmission of shocks	All the countries are involved, but Germany and Spain have not a relevant role
2011-2012 – Sovereign debt crisis	The number of connections has increased respect the benchmark «tranquil» period of time: there has been a contagion process	Italy has uniquely a follower role, in the sense that absorbs shocks, but it does not propagates them. Germany and Spain have, instead, a leading role in the shock transmission mechanism	All the countries are involved, but Germany and Spain have the most relevant role. Italy shows an high degree of vulnerability as a follower country.
Stock returns			
2008-2009 – Subprime – Lehman default crisis	The number of connections has increased respect the benchmark «tranquil» period of time: there has been a contagion process	Germany and France have a leading role in the shock transmission mechanism	All the countries are involved. Italy is directly connected only with Germany and France
2012 – Sovereign debt crisis	The number of connections has increased respect the benchmark «tranquil» period of time: there has been a contagion process	Germany and France have lost their leading role in the shock transmission mechanism; Greece is the most important leading country	All the countries are involved, but Germany and France have a less relevant role. There are direct connections between Italy and the PIGS. Italian degree of involvement in the crisis is close to the Spanish one. There is an increase of the rate of involvement of Portugal

rate of involvement of Portugal in the contagion process, in which Greece has clearly a dominant role as a leading country.

6 Conclusions

The recent financial crisis, which started with the collapse of the US mortgage market in 2007, has reinforced the concerns about the contagion effect in financial markets for both emerging and advanced economies. This paper contributes to a better understating of this phenomenon by exploring changes in cross-market connections for the sovereign debt markets and stock markets. We are interested in understanding how much contagion exists within the sovereign debt and stock markets in Europe, where contagion is defined as how different the propagation of shocks is after a large negative realization has taken place (Edwards, 2000). *Contagion* occurs when cross-country connections increase after a crisis compared to connections during tranquil periods, and then return to lower level once a new calm period emerges and hence cannot be due to fundamentals, which involve just *interdependence*. Developing an understanding of financial contagion would clearly be beneficial for policy makers hoping to manage and avoid the future spread of crises. In this paper we apply a methodology to detect contagion based on VECM cointegration and Granger causality analysis in order to measure shifts in the shocks transmission channels caused by the creation of new long-run equilibria and/or the raising of new short-run connections. Results highlight the fact that there was contagion both during Lehman crisis and sovereign debt crisis, given that the number of cross-market connections increased significantly after such crisis episodes and then reduced afterwards (at least for the Lehman episode). In particular, if we compare the timings of contagion for the two asset classes, we find that during the sovereign debt crisis (2011-2012) contagion in sovereign debt markets led the increase of correlation among stock markets, while during the Lehman default crisis (2008-2009) financial contagion in stock markets emerged before the contagion in sovereign spreads.

With regards to the equity market, results highlight that after the Lehman default, the most relevant contagion pulse over stock returns was transmitted by «core» countries (Germany and France), while during the sovereign debt crisis the contagion phenomenon hit predominantly the peripheral countries (Italy, Greece and Portugal).

In relation to sovereign spreads, peripheral countries like Italy, Ireland, Portugal, and Spain turn out to be the most involved in both the contagion occurrences which spread out after the Lehman default and the sovereign debt crises. Moreover, we find that during the sovereign debt crisis Italy has shown to be the most vulnerable country as it is the only one which does not spread any contagion links to the others and, in turn, reveals to be affected by the largest number of contagion links coming from other economies.

7 Appendix

7.1 Simple Correlation and the Identification of Contagion Windows

In Figure A1, we represent the average of the bi-variate correlations among sovereign bond spreads, which have been computed by applying a rolling indicator with a 6 month-window. The correlation time series shows a clear negative trend and it seems not to be a useful tool for the identification of contagion windows. For example, the correlation during 2011-2012 is even lower with respect to the correlation estimated during 2010, which we expect, instead, to be a more tranquil period of time. To make our results more robust, we take into consideration Forbes and Rigobon (2002) results, which provide evidence that the estimates of correlation could be biased during all during high volatility periods of time. Therefore, we also apply the dynamic conditional correlation indicator (Engle, 2002), which takes into consideration directly the influence of volatility in the estimation process. This second indicator also shows a clear negative trend.

In an analogous way, we have estimated correlation (average bi-variate rolling indicator and dynamic conditional estimator) among stock markets (Fig. A2). In this case correlation also seems not be a useful tool to individuate contagion windows, given that it tends to remain stably high during all of the examined period. Moreover, during 2011-2012

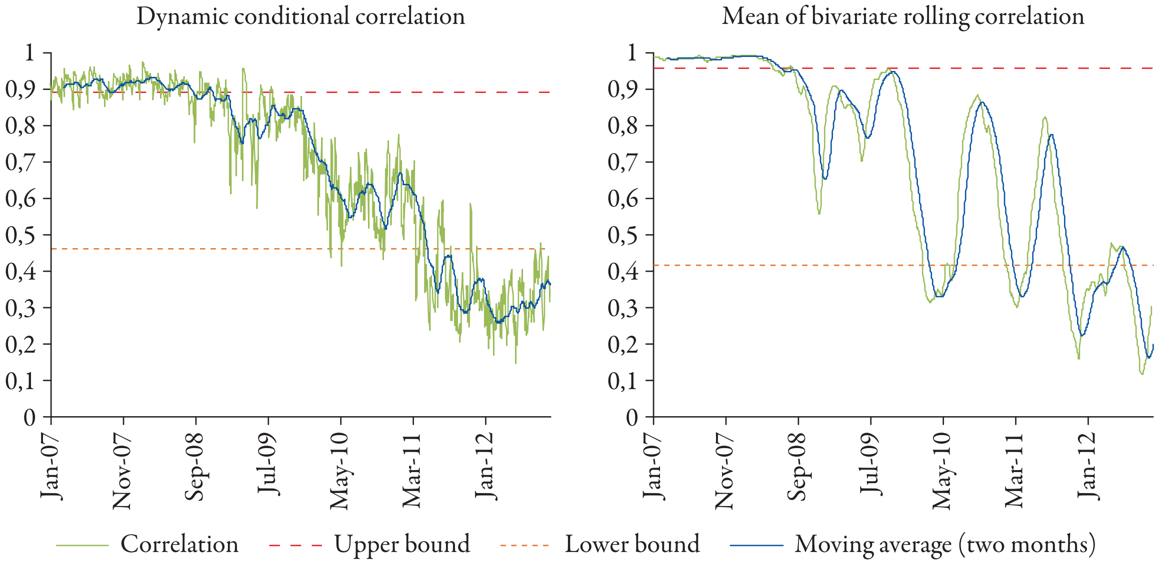

Figure A.1: Correlation among sovereign spreads.

Note: Dynamic conditional correlation has been estimated by applying Engle (2002) model on the daily changes of spread time series. Upper/lower bound corresponds to the I°/III° quartile of the correlation indicator time-series. Sovereign spreads are computed with respect to US Treasury bonds.

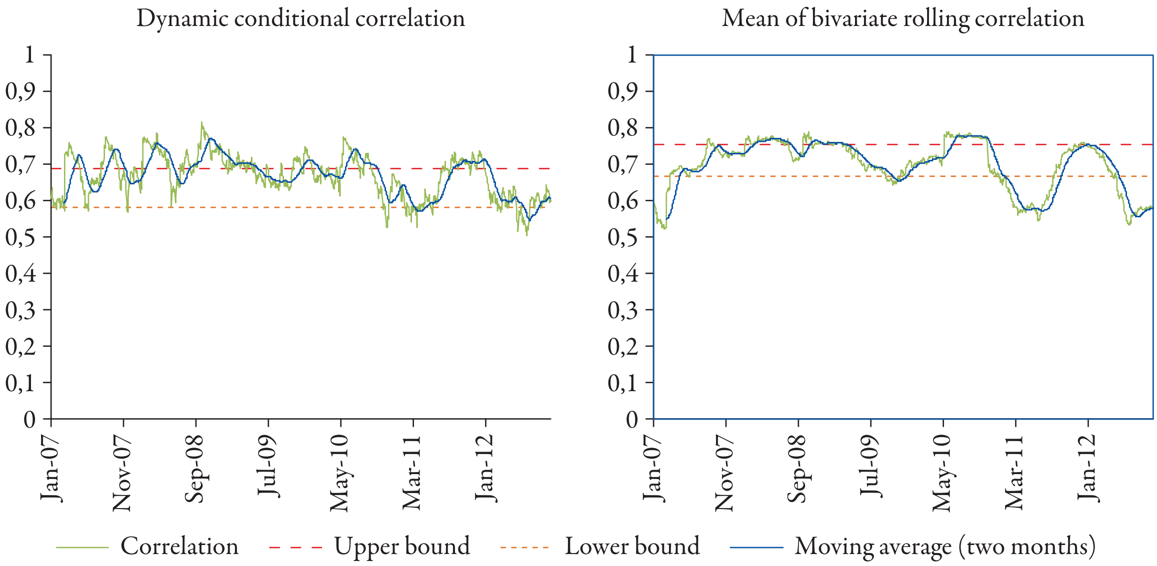

Figure A.2: Correlation among stock returns.

Note: Dynamic conditional correlation has been estimated by applying Engle (2002) model on the return time series. Upper/lower bound corresponds to the I°/III° quartile of the two correlation indicators time-series.

the degree of stock return comovements seems to remain at lower levels with respect to what has been estimated in 2010.

7.2 The Rate of Involvement Indicator

The last contagion indicator that we have used in the empirical application is based on the forecast-error variance decomposition approach (FEVD) and measures how much of the movements in one country can be explained by shocks in other countries (as before, the exercise is performed separately for European stock and sovereign bond markets). Of course, as far as the proportion of the movements explained by other countries increases, the vulnerability of the system also increases given that it is more exposed to external shocks. In accordance with the conceptual framework previously discussed, we assume that contagion occurs every time the degree of vulnerability of one country – measured as the fraction of its movements due to other country shocks – increases after a crisis period. From an econometric viewpoint, the forecast-error variance decomposition model (FEVD) measures the fraction of the forecast-error variance of an endogenous variable that can be attributed to orthogonalized shocks to itself or to another endogenous variable. It gives the portion of the movements in the dependent variables that are due to their «own» shocks, *versus* shocks to the other variables[11]. The starting point of this indicator is given by the moving-average representation of the VECM:

$$R_t = \sum_{s=0}^{\infty} C(s)\, u(t-s)$$

where the i,j-th component of $C(s)$ represents the impulse-response of the i-th country in s periods to a shock of one standard error in the j-th country and u is a orthogonalized innovation in the sense that it has an identity covariance matrix. Starting from this mathematical representation of the stock return (the same holds in the case of sovereign bonds), the variance of the *n-step* ahead forecast variance of the i-th return time series ($R_{i,\,t+n}$) is:

$$\sigma_i(n)^2 = \sum_{j=1}^{n} C_{i,1}(j)^2 + \dots + \sum_{j=1}^{n} C_{i,N}(j)^2$$

where N is the number of countries included in the sample.
As a consequence, for each country stock market i the ratio

$$w_i(k) = \frac{\sum_{j=1}^{n} C_{i,i}(j)^2}{\sigma_i(n)^2}$$

represents the portion of movements in country i due to shocks from country k, on the time horizon n. In particular, for $i = k$ we have:

$$w_i(i) = \frac{\sum_{j=1}^{n} C_{i,i}(j)^2}{\sigma_i(n)^2}$$

that is the portion of its forecast error variance which is explained by its own innovations. As a consequence, its complement to one ($1 - W_i(i)$) is the *rate of involvement indicator*, which measures the degree of vulnerability of country i, because it is the percentage of the variance of country i explained by innovations in other countries, and can be considered as a measure of country exposure to external shocks. In other words, the «rate of involvement» measures the degree of vulnerability of each country, as the degree of exposure to external shocks: it indicates how much «domestic» risk is explained by innovations in foreign countries.

[11] A shock to the i-th variable will directly affect that variable of course, but it will also be transmitted to all of the variables in the system through the dynamic structure of the VAR. Variance decompositions determine how much of the s-step-ahead forecast error variance of a given variable is explained by innovations to each explanatory variables for $s = 1, 2, \dots, T$.

7.3 VECM Multivariate Models Used to Apply the Granger Causality Test

The Granger causality test for sovereign spreads is based on the application of a multivariate cointegration model in which the dependent variable is given by the daily change of the sovereign spread. The model is[12]:

$$\Delta spread_t^k = \gamma_0 + \sum_{j=1}^{N} \sum_{i=1}^{p} \gamma_{i,j} \Delta spread_{t-1}^j + \alpha_k \beta' \begin{bmatrix} \Delta spread_{t-1}^{UK} \\ \Delta spread_{t-1}^{Germany} \\ \Delta spread_{t-1}^{France} \\ \Delta spread_{t-1}^{Italy} \\ \Delta spread_{t-1}^{Spain} \\ \Delta spread_{t-1}^{Greece} \\ \Delta spread_{t-1}^{Portugal} \\ \Delta spread_{t-1}^{Ireland} \end{bmatrix}$$

where α_k is the coefficient which measures the speed of convergence to the long-run equilibrium, while β is the vector which contains the parameters of the common stochastic trend; lastly, both k and j represent country indexes: k,j = *Germany*, *France*, *Italy*, *Spain*, *Greece*, *Portugal*, *Ireland*, *the KU* and N is the number of countries included in the sample ($N = 8$). The above equation comprises the error correction term $\alpha_k \beta'$ because Engle and Granger (1987) and Granger (1988) have stated that in the presence of cointegration, causality tests, which ignore the error correction term (ECT) derived from the cointegration relationship are mis-specified, and suggested to re-parameterize the model in the equivalent error correction model form (VECM). If the time series are not co-integrated, $\alpha_k \beta'$ is equal to zero and the model becomes a VAR(p)[13].

VECM-based tests allow us to differentiate between two types of causality: the short-run dynamics of the VAR and the disequilibrium adjustment of the ECM. In particular, the F-test on the estimated coefficients $Y_{i,j}$ provides evidence regarding a short-term adjustment dynamics. The t-test of the estimated coefficient $\alpha_k \beta'$ provides evidence for the existence of an arbitrage-type error correction mechanism that drives the variables back to their long-term equilibrium relationship that is embodied in the cointegration vector.

The application of the Granger causality test allows us to find relevant short term connections among markets and to identify the direction of these connections. For instance, if at least one $Y_{i,j}$ for $i = 1,.., p$ is significantly different from zero, this means that $\Delta spread^j$ influences $\Delta spread^k$.

The Granger causality test for the stock markets allows us to individuate short-term cross-market links and it is based on the estimation of the multivariate co-integration model in which the dependent variable is given by the stock return:

[12] We have verified that the spread is not stationary in the levels on the basis of the Augmented Dickey Fuller test.
[13] The order p of the model is based on the application of the HQIC and SBIC information criteria.

$$R_t^k = v_0 + \sum_{i=1}^{p} \theta_i^{USA} R_{t-1-i}^{USA} + \sum_{j=i}^{N} \sum_{i=1}^{p} v_{i,j} R_{t-i}^{j} + \alpha_k \beta^{`\hat{e}} \begin{bmatrix} \log(P_{t-2}^{USA}) \\ \log(P_{t-1}^{UK}) \\ \log(P_{t-1}^{Germany}) \\ \log(P_{t-1}^{France}) \\ \log(P_{t-1}^{Italy}) \\ \log(P_{t-1}^{Spain}) \\ \log(P_{t-1}^{Greece}) \\ \log(P_{t-1}^{Portugal}) \\ \log(P_{t-1}^{Ireland}) \end{bmatrix}$$

where, as in the previous case, k,j = *Germany*, *France*, *Italy*, *Spain*, *Greece*, *Portugal*, *Ireland*, *UK* and N is the number of countries included in the sample ($N = 8$). As we have already underlined for sovereign spreads, if the time series are not co-integrated, the model becomes a VAR(p). The inclusion of US stock returns in the model to test for Granger causality is necessary because, as it is stated in the empirical literature, linkage patterns among European markets may be distorted when the influence of the US market is not taken into consideration (Yang *et al.*, 2003; Bekaert *et al.*, 2012). Moreover, the inclusion of the US market improves the level of symmetry between stock and sovereign bond models given that the US is also implicitly included in the sovereign bond application (the spread is computed with respect to US Treasuries). The inclusion of the US stock index returns makes it necessary to take into consideration the synchronization issue. Indeed, the US stock market operates in a different time zone with respect to European countries and it is characterized by different opening and closing times. In particular, trading in the US stock markets today impacts upon the European markets the following trading day. In line with the approach most frequently applied in the literature (Malliaris and Urrutia, 1992), we incorporate the synchronization issue directly in the specification of the econometric model, by considering the US stock index return with one lag of delay. The application of the Granger causality test allows us to find relevant short term connections among markets and to individuate the direction of these connections. For instance, if at least one $v_{i,j}$ for $i = 1, .., p$ is significantly different from zero, this means that R^j influences R^k.

7.4 Connections among Sovereign Bond Markets

Table A.1: Significant connections among sovereign spread markets

Leading / Follower	Germany L	Germany S	France L	France S	Italy L	Italy S	Spain L	Spain S	Greece L	Greece S	Portugal L	Portugal S	Ireland L	Ireland S	UK L	UK S	Tot
April 2008 – November 2008 – «tranquil» period of time																	
Germany	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
France	–	–	–	–	–	–	1.1**	–	–	4.0**	–	–	–	–	–	–	2
Italy	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
Spain	–	–	–	–	–	–	–	–	–	2.9*	–	–	–	–	–	–	1
Greece	–	–	–	–	–	–	0.04**	–	–	–	0.4**	–	0.4**	–	–	–	3
Portugal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
Ireland	–	–	–	–	3.5**	–	–	–	–	–	–	–	–	–	–	–	1
UK	–	–	–	3.2*	–	–	1.5**	–	–	–	–	–	0.01**	–	–	–	3
Tot	0		1		1		3		2		1		2		0		10
December 2008 – July 2009 – Lehman default crisis																	
Germany	–	–	–	–	–	–	–	–	–	–	–	3.2*	–	–	–	–	1
France	–	–	–	–	0.6**	–	–	–	–	–	–	4.1**	–	–	–	–	2
Italy	–	–	–	–	–	–	–	–	0.7*	–	–	3.1*	–	4.2**	–	–	3
Spain	–	–	–	–	3.5**	–	–	–	–	–	–	–	–	2.8*	–	–	2
Greece	–	–	0.7**	–	2.1**	–	–	–	–	–	–	4.2**	–	10***	–	–	4
Portugal	–	–	–	–	–	–	–	–	–	–	–	–	–	6.7**	–	–	1
Ireland	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
UK	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
Tot	0		1		3		0		1		4		4		0		13
May 2010 – December 2010– «tranquil» period of time																	
Germany	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
France	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
Italy	3.4**	–	–	–	–	–	–	–	–	–	2.8**	–	0.5**	5.6***	–	–	3
Spain	–	–	–	–	–	–	–	–	–	3.7*	–	–	1.1**	5.5***	–	–	2
Greece	–	–	–	–	2.6**	–	–	–	–	–	–	–	–	–	–	–	1
Portugal	–	–	–	–	2.8**	–	–	–	–	–	–	–	–	–	–	–	1
Ireland	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
UK	–	–	–	–	–	–	–	–	–	–	–	–	–	4.0***	–	–	1
Tot	1		0		2		0		1		1		3		0		8
November 2011 – May 2012 – Euro area sovereign debt crisis																	
Germany	–	–	–	–	–	–	–	–	–	–	–	–	–	4.6**	–	–	1
France	–	–	–	–	–	–	–	3.1*	–	–	–	–	–	–	–	–	1
Italy	–	3.58*	–	11.5***	–	–	–	–	–	–	–	5.9***	–	–	–	–	3
Spain	–	10.3***	–	6.6***	–	–	–	–	–	–	–	10.4***	–	–	–	–	3
Greece	–	–	–	–	–	–	–	3.8*	–	–	–	–	–	–	–	–	1
Portugal	–	–	–	–	–	–	3.2**	–	–	–	–	–	–	3.0*	–	–	2
Ireland	–	3.3*	–	–	–	–	–	–	–	3.3*	–	–	–	–	–	–	2
UK	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
Tot	3		2		0		3		1		2		2		0		13

Note: L = long-term relation (detected by applying the bi-variate cointegration test); S = short-term relation (detected by applying the Granger causality test). For the long- term relations we report the Johansen cointegration statistic; for the short- term connections we report the F-test statistic. «***» indicates that we reject the null hypothesis of absence of long-run or short-run relations at the 1% level; «**» at the 5% level; «*» at the 10% level. The direction of the long-term relation is identified by applying the Gonzalo-Granger statistic. «–» indicates that the test has not detected a significant connection between the examined couple of markets.

7.5 Connections among Stock Markets

Table A.2: Significant connections among stock markets

October 2006 – March 2008– «tranquil» period of time																	
Leading / Follower	Germany		France		Italy		Spain		Greece		Portugal		Ireland		UK		Tot
	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	
Germany	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
France	–	–	–	–	–	–	–	–	–	–	–	3.0*	–	–	–	–	1
Italy	–	–	–	–	–	–	–	6.3**	–	–	–	–	–	–	–	–	1
Spain	–	–	–	–	–	–	–	–	–	–	–	3.9**	–	–	3.6**	–	2
Greece	–	–	–	–	–	–	–	–	–	–	–	4.1**	–	–	–	–	1
Portugal	–	–	1.1**	–	–	–	–	3.9**	–	3.8**	–	–	–	–	1.1**	–	4
Ireland	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
UK	3.3**	–	0.6**	–	–	–	–	–	–	–	–	4.2**	–	–	–	–	3
Tot	1		2		0		2		1		4		0		2		12
March 2008 – July 2009– Subprime and Lehman default crisis																	
Leading / Follower	Germany		France		Italy		Spain		Greece		Portugal		Ireland		UK		Tot
	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	
Germany	–	–	–	6.5**	–	–	–	–	–	8***	–	–	–	–	–	–	2
France	1.5**	5.2**	–	–	–	–	–	–	1.6**	–	–	–	1.2**	–	–	–	3
Italy	1.7**	–	1.4**	3.9**	–	–	–	–	–	–	–	–	–	–	–	–	2
Spain	–	3.9*	–	6.3**	–	–	–	–	1.4**	–	–	–	–	–	–	–	3
Greece	–	8.3***	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Portugal	–	8.5***	–	2.8*	–	–	–	–	–	–	–	–	–	–	–	–	2
Ireland	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
UK	1.2**	–	–	–	–	–	–	–	1.5**	–	–	–	1.2**	–	–	–	3
Tot	6		4		0		0		4		0		2		0		16
June 2010 – January 2011– «tranquil» period of time																	
Leading / Follower	Germany		France		Italy		Spain		Greece		Portugal		Ireland		UK		Tot
	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	
Germany	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
France	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.5**	–	1
Italy	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
Spain	–	–	–	–	–	–	–	–	–	–	1.5**	–	–	–	–	–	1
Greece	–	–	–	–	–	–	–	4.8**	–	–	–	–	–	–	–	–	1
Portugal	–	–	–	–	–	–	–	2.9**	–	–	–	–	–	–	–	–	1
Ireland	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
UK	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
Tot	0		0		0		2		0		1		0		1		4
January 2012 – September 2012– Sovereign debt crisis																	
Leading / Follower	Germany		France		Italy		Spain		Greece		Portugal		Ireland		UK		Tot
	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	
Germany	–	–	–	–	–	2.7*	–	–	–	–	–	–	–	–	–	3.4*	2
France	–	–	–	–	–	–	–	–	–	2.7*	–	–	–	–	–	3.4*	2
Italy	–	–	–	–	–	–	3**	–	–	3.2*	–	–	2.1**	–	–	–	3
Spain	–	–	–	–	–	–	–	–	–	–	–	–	2.7**	–	–	–	1
Greece	–	–	–	–	–	–	–	2.8*	–	–	–	–	–	–	–	–	1
Portugal	–	–	3.0**	–	3.2**	–	–	–	–	3.9**	–	–	–	–	2.8**	–	4
Ireland	–	–	2.6**	–	–	–	–	–	–	–	3.2**	–	–	–	3.3**	–	3
UK	–	–	–	–	–	4.8**	–	–	–	–	–	–	–	–	–	–	1
Tot	0		2		3		2		3		1		2		4		17

Note: L = long-term relation (detected by applying the bi-variate cointegration test); S = short-term relation (detected by applying the Granger causality test). For the long- term relations we report the Johansen cointegration statistic; for the short- term connections we report the F-test statistic. «***» indicates that we reject the null hypothesis of absence of long-run or short-run relations at the 1% level; «**» at the 5% level; «*» at the 10% level. The direction of the long-term relation is identified by applying the Gonzalo-Granger statistic. «–» indicates that the test has not detected a significant connection between the examined couple of markets.

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