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Consob

00198 Rome

Via G.B. Martini, 3

t 06.8477.1

f 06.8477612

e studi_analisi@consob.it

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Financial contagion during Lehman default and sovereign debt crisis

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*M. Gentile, L. Giordano**

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 as contagion, that is co-movements among asset prices which have been excessive respect to fundamentals. 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. Although there is still wide disagreement among economists about what contagion is exactly and how it should be tested empirically, a common approach consists of identifying breaks in the international transmission of shocks indirectly, inferring them from a significant rise in the correlation of asset returns across markets and countries. Our study extends on this conventional measures of contagion by directly investigating changes in the existence and the directions of causality among a sample of Euro area countries during the recent Lehman default and sovereign debt crisis. To test for contagion, we apply a three steps 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.

JEL Classification: G01, G15.

Keywords: contagion, Euro area sovereign debt crisis, sovereign bond spread, stock market.

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Contents

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 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 only four years the EMU sovereign bond markets went from a situation of high stability to their current situation of turmoil.

However, the severity and the spread of the crisis, as well as the speed of this spread and its geographical reach, are difficult to explain by only pointing to "fundamentals". "Contagion" became the catchword for such phenomena and is now widely being used to describe the events around the crisis of European Monetary System in 1992/1993, the "tequila hangover" in 1994, the Asian crisis in 1997, the Russian crisis in 1998 and, more recently, 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 there is widespread disagreement about what this term entails, the largest body of theoretical definitions hinges on the idea that *contagion is the amount of co-movement among asset prices which exceeds what is explained by fundamentals*. Several specifications of this basic definition have historically been developed manly to accomplish a feasible econometric measurement[1].

Our paper defines contagion as a significant increase in cross-market co-movements after a shock to one country or group of countries beyond what would be justified by fundamentals (Dornbush *et al.*, 2000). 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. It is *contagion* only if cross-market co-movements increase significantly after the shock. If co-movements do not increase significantly, then any continued high level of market correlation suggests strong linkages between the two economies that exist in all state of the world; to refer to this situation we use the term *interdependencies*.

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

1 For a discussion of a full set of definitions and their advantages and disadvantages, see Forbes and Rigobon (2001).

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 shocks across countries.

If one follows this narrow definition, the task of empirical contagion studies is to investigate whether or not channels and intensities of shock propagation across countries are changed in certain crises periods.

In the empirical literature, contagion has been often measured using stock market returns, interest rates, exchange rates, or linear combinations of these variables. Four major strategies have been employed in the literature to identify contagion: i) correlation among asset prices; ii) conditional probability of crises; iii) volatility changes and iv) co-movements of capital flows. Among these four groups, our study is related to the analysis of asset prices correlation and therefore contagion is detected as a significant increase of the co-movement among asset prices after a shock or crisis periods.

This paper provides evidence on the changes in crisis causation among euro area countries by applying a three step Granger causality/Vector error correction model (VECM) methodology on sovereign bond spreads and stock indexes: contagion is revealed by the number of co-integrating vectors and the extent of Granger-causality that exists among countries. Moreover, we establish 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.

The analysis relates to a sample of Euro area countries over the period January 2003-September 2012 and the definition of contagion that we retain in our paper is that given by Forbes and Rigobon (2002): «*Contagion is* a *significant increase in the co-movement between assets during a period of crisis, compared with a tranquil period; while if there is a high level of market co-movement in all periods it is the case for interdependence*».

This definition of contagion entails an intensification or change in the transmission of shocks between markets and it requires a structural break and the identification of a tranquil, pre-event period. Therefore, the presence of contagion assumes that the transmission of a shock is made possible through investors' anticipation behaviour and information asymmetry (Calvo, 1999). Furthermore, transmission mechanisms during a crisis are forcibly different from those in a stable period.

The key concern about contagion is that it undermines the very assumption of portfolio analysis. Markets that were assumed (estimated 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.

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 soothe the market sentiments ought to be priority. Correct differentiation between these causes is a key to tackling financial market contagion.

Our results reveal the fact that causality patterns change in the crisis period compared to the tranquil one; this result suggesting evidence that contagion effects have strongly influenced asset price dynamic over the two recent crisis episodes.

To our knowledge, no empirical research takes into account both sovereign debt and stock markets simultaneously. Our study tries to adopt a more comprehensive approach to get some insights on different speed and pattern of contagion transmission across EU 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 Contagion: definition, theories, and measurement

2.1 Definitions of financial contagion and empirical literature

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. Is it the "normal" or "usual" propagation of shocks, or is it the transmission that takes place under unusual circumstances?

In spite of significant theoretical and empirical interest in the topic 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 definition used in the early stage of the research in this topic.

Under such 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 fundamental affects one another. These theories are usually based on standard transmission mechanisms, such as trade, monetary policy, and common shocks (ex.: oil prices).

In the second and more focused definition of a more 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[2]. 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. Herding behavior is usually said to be responsible for co-movement beyond that explained by fundamental linkages.

Contagion occurs when cross-country correlations increase during "crisis times" relative to correlations during "tranquil times" because this can only be due to factors unrelated to fundamentals, since fundamentals cannot change in few months. In fact, Forbes and Rigobon (2002) argue that «*contagion is a significant increase in cross-market co-movements after a shock*». This definition is sometimes referred as "shift-contagion". Forbes and Rigobon (2001) stress that this notion of contagion excludes a constant high degree of co-movement in a crisis period, otherwise markets would be just interdependent[3].

In our study we follow this more focused definition of contagion and in this section we will discuss the major theoretical and empirical contributions on such topic.

Historically, the first strain of our contagion definition developed in the literature was closely linked to the original definition that appeared in the finance literature (King and Wadhwani, 1990). The intuition is that if there is a shift in the strength of the propagation of shocks during a period of turmoil relative to a period of tranquility, then that shift is considered contagion. The empirical tests of this definition used correlation coefficients. The theory was that a change in the estimated correlation of two countries' market movements implied a shift in the strength of the transmission of shocks from one country market to another. Later, similar tests were performed with the use of more sophisticated methods – principal components, cointegrating relationships, and so on. All of these tests have the same spirit: to determine whether or not the propagation of shocks is stable around the time of a currency, market, or economic crisis. If the propagation of shocks is not stable, then this instability is considered to be an indicator that contagion has occurred.

Masson (1998) has labeled such unanticipated situations as "pure contagion". They are to be distinguished from "simple contagion" caused by "monsoonal

2 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.

3 In addition to the abovementioned approaches to explain financial contagion, we can also rely on some other and even more extreme definitions of this phenomenon. For example according to Sola *et al* (2002) there is contagion if the probability of having a crisis at home is equal to one if the crisis hits another market; on the other hand Bae *et al* (2003) consider coincidence of extreme return shocks across countries as evidence for contagion.

effects" and "linkages". "Monsoonal effects" are random aggregate shocks that are hitting a number of countries in a similar way while "linkages" are normal interdependencies, such as those produced by trade and financial relations between countries. Only when the transmission process itself changes when entering crises period, we talk of contagion in the sense of Masson's "pure contagion".

Although this approach seems restrictive, it has two important advantages. First, it provides a straightforward framework for testing contagion by simply comparing co-movements between two markets (such as cross-market correlation coefficients) during a relatively stable period with co-movements immediately after a shock or crises. Contagion is a significant increase in cross-market co-movements (whatever these connections are measured) after the shock.

A second benefit of this definition is that it provides a straightforward method of distinguishing between alternative explanation of how contagion emerges and it is transmitted across markets. In this matter, there is an extensive theoretical literature on the propagation of contagion, which, in most of the cases, assumes that investors behave differently after a crisis.

As said before, the initial literature has generally been divided as to whether transmission through real or financial channels constitutes contagion[4]. Later researchers have tended to adopt the semantic that "pure" contagion is unrelated to these transmission channels, and is hence entirely captured by shift in market actor's perceptions and attitudes towards risk. As said before, the transmission of shocks through the first two linkages – financial or real – is refereed to merely as *interdependence* or spillovers.

"Pure" contagion is, instead, a situation in which investors change their assessment of the rules under which international finance takes place (Claessens *et al.*, 2001). Other examples of theories of why contagion takes places are those advocating self-validating losses in confidence that can push economies from a "good" into a "bad" equilibrium. An example is Obstlfeld (1994), who first constructed a so-called "second-generation currency crisis" model for the EMS crises[5]. A contribution with an explicit emerging market focus is Sbracia and Zaghini (2001) who develop a second-generation currency crisis model where a sudden shift in speculator's behavior can trigger a currency devaluation without any prior deterioration of economic fundamentals.

Summing up, all the above models that explain (pure) contagion advocate the role of multiple equilibria in explaining why the channels and intensity of shocks propagation across countries may change in crisis periods. The critical implication is

4 Real linkages have been identified by the theoretical literature to be shocks propagated via trade, policy coordination, country reevaluation, and random real global shocks (the so called non crisis-contingent theories), whilst financial linkages include multiple equilibria due to endogenous liquidity shocks, political contagion, and random global monetary shocks (the crisis-contingent theories). For an overview of this literature, see Forbes and Rigobon (2002).

5 The term "second-generation currency crises" have been introduced by Eichengreen *et al.* (1996a) for models focusing on a self-fulfilling crisis mechanisms in order to distinguish these approaches from earlier models that focus on the role of fundamentals.

that the transmission mechanism during (or directly after) the crisis is inherently different than that before the shock. The crisis causes a structural shift, so that shocks are propagated via channel that did not exist in stable periods.

There is one important reason why many economists focus on the specific definition of (pure) contagion. A critical principle of investment strategy is that most economic disturbances are country specific, therefore international diversification should substantially reduce portfolio risk and increase expected returns. If market correlations increase after a negative shock, however, this would undermine much of the rationale for international diversification.

Even this narrow definition of (pure) contagion can incorporate a number of different types of cross-market connections. For example, connections could be measured through the correlation in asset returns, the volatility change or the probability of a speculative attack. Among such mentioned major strategies that have been applied in empirical studies to discriminate *pure contagion* from *interdependencies* our approach is related to the analysis of asset price co-movement and in the following we briefly review the relevant empirical literature, keeping in mind that contagion is an unobservable shock and therefore most empirical techniques have problems dealing with omitted variables and simultaneous equations.

Forbes and Rigobon (2001) have suggested to discriminate empirically between contagion and interdependencies by testing whether or not cross-market correlation increase statistically significantly in crisis periods. If yes, crises-contingent theories have a point, if not interdependencies are responsible for the spread of crises. Forbes and Rigobon (2002) argue that simple correlations are biased due to the presence of heteroskedasticity, endogeneity, and omitted variables.[6] 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*»[7].

In the European Exchange Rate Mechanism (ERM) context, Favero and Giavazzi (2000) find evidence for contagion with regard to the spreads between German short-term interest rates and the interest rates of some of the European countries involved in a number of country-specific shocks.

Baig et Goldfajn (1999) using the mentioned definition of contagion (co-movements in financial variables in excess of those that can be explained by co-movements of fundamentals) stress that, to identify contagion it is essential to distinguish between fundamentals and non-fundamentals-driven co-movements. Empirically, if after controlling for fundamentals one finds significant co-movement between the markets of two countries, then the remaining unexplained correlation may be attributed to contagion.

6 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.

7 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 can empirically not be generalized.

In the context of the Asian crisis, Baig and Goldfajn (1999) perform cross-market correlations for exchange rates, stock returns, interest rates, and sovereign bond spreads using Forbes and Rigobon (2002) methodology. They find mixed evidence of an increase in correlation in exchange rate, stock market returns and interest rates co-movements, though overwhelming evidence for contagion when using sovereign spreads. They interpret this result arguing that, since spreads are directly reflecting the risk perception of financial markets, pure contagion may be «*solely the result of the behavior of investors or other financial agents*» as argued by Claessens *et al.* (2001).

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 beginning of the Greek debt crisis in October 2009. They conclude that in European countries «*both contagion and interdependence occurred*».

Gomez-Puig and Sosvilla-Rivero (2011) provide empirical evidence of the existence of sub-periods of contagion phenomenon during different periods since 1999 for EMU countries, by applying the Granger causality test among all pair-wise selected countries. 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 significantly risen during the recent crises in sovereign debt markets from 2009, providing evidence of an increase in the contagion between them.

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 during crises periods relative to tranquil ones constitutes evidence for contagion. Yang, Kolari and Min (2002) have examined both long–run and short-run relations among the U.S., 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) put on evidence 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.

Gilmore and McManus (2002) explore whether emerging equity markets of Central Europe are segmented from the US and, hence, provide scope for diversification. Their paper examines the short and long-term relationships between the US stock market and three Central European markets. Low short-term correlations between these markets and the US are found. Application of the Johansen cointegration procedure indicates that there is no long-term relationship. The Granger-causality test does reveal a causality running from the Hungarian to the Polish market, but none with the US. Overall, the results suggest that US investors can obtain benefits from international diversification into these markets.

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*.

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. 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, whereas the UK is the most immune to contagion.

2.2 Transmission channels

Before concluding this section, we will discuss in brief the more relevant empirical literature on transmission channels because the understanding of the financial contagion phenomenon is closely related to its transmission channels.

Authors of papers on financial crises have not yet achieved consensus on the channels through which contagion spreads and hence on why contagion takes places. Several trade issues, the macro environment, the common lender, market psychology amongst others, have been considered as determinants of the degree of contagion. The different opinions are well summarized by Dornbusch *et al* (2000): «*not only the exact causes and channels of contagion are not known, neither are the precise policy interventions which can most effectively reduce it*».

As said before, in the late literature the distinction between *contagion* and *interdependence* has been made according to the transmission channels of each (see Rigobon 2002 and Kleimeier *et al.* 2008). If crises are transmitted through stable fundamental linkages, then only countries with weak economic fundamentals will be affected while good fundamentals can offer protection. On the other hand, if irrational behaviour by the agents (in the form of speculative attacks, financial panic and/or herd behaviour) is the transmission force, then even countries with good fundamentals can be seriously affected. In the former case we have only *interdependence* and not contagion between countries, while in the latter case we have true *contagion*.

On the other hand, *interdependence* can be due to at least three types of "fundamental" linkages: 1) financial; 2) real; 3) political. Since our adopted definition of "shift" contagion relies on «*a significant increase in cross-market co-movements after a shock*» which is not related to fundamental linkages, the only transmission channel which could explain *contagion* is the behavioral one, because we assume that fundamental linkages cannot change all of a sudden in the few months after a shock has occurred. The others are responsible for *interdependence*.

It can be argued, therefore, that investors' behavior, whether rational or irrational, allows shocks to spill over from one country to others. The literature differs on the scope of rational versus irrational investor behavior, both individually and collectively (Pritsker, 2000). First, investors can take actions that are *ex ante* individually rational but that lead to excessive co-movements – excessive in the sense that they cannot be explained by fundamentals. Through this channel, which can broadly be called investors' practices, contagion is transmitted by the actions of investors outside the country, each of whom is behaving rationally. Conceptually, this type of investor behavior can be further sorted into problems of liquidity and incentives and problems of informational asymmetry and market coordination. Second, cases of multiple equilibria, similar to those in models of commercial bank runs, can imply contagious behavior among investors. Third, changes in the international financial system, or in the rules of the game, can induce investors to alter their behavior after an initial shock.

Many authors have found that such fundamental links (and common shocks) do not fully explain the relationship and changes in relationships among countries (Banerjee, 1992; Calvo and Mendoza, 2000). That being the case, herding behaviour is suggested as a reason for spillover effects between countries. Herding behaviour arises when information about countries' fundamentals is incomplete and asymmetric, there are no restriction for capital mobility and information is too costly for the less sophisticated investors. So instead of making expenses for getting information these rather uninformed investors are watching the action of others, supposedly well informed, investors and then trying to follow them as they think these actions reflect the future price changes. It follows that the whole market moves jointly. In reality, those supposedly well informed investors may not be acting based on their information about countries' fundamentals, but just adjusting their portfolios after being damaged by a crisis elsewhere. In the circumstances of such kind of herd behaviour and assuming the existence of multiple equilibria, even countries with sound fundamentals are not protected.

Support for the idea of the transmission of crises based on herd behaviour has been found by many authors. Alvarez-Plata and Schrooten (2003), examining the 2002 Argentina crisis, show that the pull effect caused by investors all behaving in the same way made economic fundamentals unimportant and led to the rapid withdrawal of capital from economies hit by shocks, and possibly even from entire regions.

Pindyck and Rotemberg (1990 and 1993) find that after taking into account common fundamentals there is still residual co-movement across stocks with very different industry and idiosyncratic fundamentals. Eichengreen, Rose and Wyplosz (1996b) highlight that the countries that came under speculative attack during the 1992 ERM (European Exchange Rate Mechanism) crisis had heterogeneous macroeconomic fundamentals, and only in some cases could the attack be justified by the fundamentals. Moussalli (2007) and Woo (2000) also have argued that herding is the main channel for spillover effects between countries.

Summing up, all these results point to the important role played during the crisis by investors' behavior, whether (individually) rational or (collectively) irrational.

3 Data and methodology

In this section we perform a three-steps econometric analysis to test for contagion in two shocks episodes occurred in the last decade for a sample of European countries.

The sample is made of eight European countries (France, Germany, Greece, Ireland, Italy, Portugal, Spain and United Kingdom) and we test the co-movements across countries using two type of assets (equities and sovereign bonds).

As regards to the sovereign bond, we use the sovereign spreads time series computed as the difference between the selected countries sovereign bond yields and the corresponding US-Treasury yield, which is a measure of country-specific credit risk and therefore can be interpreted as indicator of the effects of the crisis as perceived by the international market (Sander and Kleimeier, 2003)[8].

As regards to 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 few days. All data (sovereign bond spreads and stock index prices) are retrieved from the Datastream databank and the time span of our time series goes from the first of January 2003 to the 30th of September 2012.

To individuate significant connections among couple of markets, we will apply two econometric techniques. The bivariate Johansen cointegration test allows us to identify relations between couples of markets which lead to slow price adjustment processes (long-run connections). The Granger causality test, instead, individuates relations which have a short-term influence in the price discovery process (short-run connections).

The methodology that we are going to apply has been planned on the basis of our definition of contagion as significant increase of the total number of cross-

8 We have chosen bonds that are similar across countries according to their maturity. For the sake of results comparability, we selected bond on 10 years maturity for all countries over the whole sample period.

market connections around the two shocks in the period analyzed (Lehman default and sovereign debt crisis). So in order to test for contagion we have to identify "crisis" and "tranquil" periods of time and we have to make a comparison among the number of significant relations in the two detected windows.

The three-step procedure we are going to implement will give, as results, three different indicators which together concur to asses contagion phenomenon in Europe.

First we use bivariate dynamic cointegration analysis to test if, in the time period analyzed, there has been the creation of new long-run equilibrium conditions among countries through the application of dynamic rolling cointegration analysis for each pair of countries. Any increase of the percentage of co-integrated countries over the total number of possible pairs signals a shift of the shock transmission channels and represents the first indicator of potential contagion. 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 conjecture of the time periods during which the contagion process could have started to spread out during the two financial crises analyzed (Lehman's default and sovereign-debt crises).

Subsequently, through the Granger causality test and VECM/Gonzalo-Granger statistic we evaluate the significance of short-run connections among countries in addition to the long-run equilibrium conditions detected in the previous step by cointegration analysis. Moreover, Granger causality methodology detects the *versus* of these connections and, consequently, it allows to examine how shocks are transmitted through countries[9]. An increase of Granger-causality connections detected after a crisis period is a signal of contagion occurrence. Alongside to the above short-run *versus* of the connections we are interested in detecting the log-run *versus* of the countries' connections and to this end we implement the Gonzalo-Granger statistic (by using the results of cointegration analysis of the pervious step) which allows to identify the direction of connections in the crisis episodes.

Finally, we apply the *variance decomposition* 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, the increasing vulnerability after a crisis period is considered as evidence of 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).

9 Indeed, the application of the Granger causality test detects whether past values of a stock index or sovereign spread can predict future values of other stock indexes or sovereign spreads. This estimation is conducted separately for all sub-periods ("contagion windows") detected in the first step.

3.1 Bivariate dynamic cointegration analysis

As a first step of our analysis we perform a pairwise countries rolling cointegration estimation for the selected asset prices time series (government bond spreads and stock returns) in order to verify if there has been contagion during the sample period by making a comparison between the number of long-run relations detected before and after the crisis episodes.

From an econometric viewpoint we run regressions in order to determine the number of cointegrating equations in a vector error-correction model (VECM). Following Johansen (1988), the model we refer is the VECM(k)[10]:

$$\varDelta X_t = \eta_X + \sum_{i=1}^{k} \lambda_{X,i} \varDelta X_{t-i} + \sum_{i=1}^{k} \gamma_{X,i} \varDelta Y_{t-i} + \alpha_1 \beta' \begin{bmatrix} X_{t-1} \\ Y_{t-1} \end{bmatrix} + \varepsilon_{X,t}$$

$$\varDelta Y_t = \xi_Y + \sum_{i=1}^{k} \lambda_{Y,i} \varDelta Y_{t-i} + \sum_{i=1}^{k} \gamma_{Y,i} \varDelta X_{t-i} + \alpha_2 \beta' \begin{bmatrix} X_{t-1} \\ Y_{t-1} \end{bmatrix} + \varepsilon_{Y,t} \tag{1}$$

where $\varDelta X_t$ and $\varDelta Y_t$ are daily changes of sovereign spreads or stock returns referred to markets X and Y, X_t and Y_t are the correspondent sovereign spread and log-price. In particular, the long-run impact matrix can be expressed as $\varPi = \alpha\beta'$, where $\alpha' = [\alpha_1, \alpha_2]$, and $[\varepsilon_X, \varepsilon_Y]$ is a vector of white noise processes. The vector of coefficient β contains the parameters of the common stochastic trend, while α_1 and α_2 measure the speed of convergence. In particular, $\beta' \begin{bmatrix} X_{t-1} \\ Y_{t-1} \end{bmatrix}$ represents a common stochastic trends towards which price dynamic slowly converges.

The Johansen cointegration test mainly relies on the assumption that the rank of $\varPi$ equals the number of co-integrating vectors. If the matrix $\varPi$ has rank r there are r cointegrating relations. When $r=0$, there is, instead, no long-run relation among international markets and the equation (1) would be reduced to a vector autoregressive model VAR(k).

The number of co-integrating relations is given by the number of non-zero eigenvalues of the impact matrix $\varPi$. The Johansen procedure proposes two tests to estimate the number of cointegration relationships (Johansen, 1991): the "*maximal eigenvalue test*" and the "*trace test*". Both tests assume that the null hypothesis implies that there are, at most, r cointegration vectors. While the *max-eigenvalue test* assumes, as the alternative hypothesis that there are exactly $r + 1$ cointegration vectors, the alternative assumption, in the case of *trace test*, is that there are more than r cointegration vectors. If the results of the tests are contradictory, we retain the values of the *trace test*, which is considered as a more powerful test[11].

10 We provide econometric details for the case of stock indexes. The same methodology holds in the case of sovereign bond spreads.

11 As concerns the cointegration rank which is the most important steps in the cointegration analysis, we choose the approach suggested by Juselius (2007) in which the choice of rank should take into account all relevant information given by different criteria (*trace test* statistics, *root of the companion matrix*) and especially the economic relevance of the results.

To detect possible contagion periods, we dynamically apply the above Johansen cointegration test between all the possible couple of countries[12] with a rolling window of 1,000 days[13], by computing at each step *t* of the procedure the following rolling indicator of cross-country connections:

$$Percentage\ of\ cross-country\ connections_t = \frac{Number\ of\ long\text{-}run\ relations_t}{Maximum\ number\ of\ long\text{-}run\ relations\ among\ all\ countries} * 100.$$

In order to discriminate between crises periods and tranquil periods we identify as crisis periods those 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 15th percentile of the distribution (Caporin *et al.*, 2012). By comparing these highest and lowest percentiles we confirm or reject our *a priori* assumptions about the timing of the two crisis episodes investigated.

As previously said, contagion occurs when cross-country co-movements – here proxied by the percentage of cointegrated countries, what we call *cross-country connections* – increase during the crisis periods relative to cross-country connections during the tranquil periods.

3.2 Directionality of shock transmission

The second step is the Granger analysis performed to study the contagion effect by directly investigating changes in the existence and the directions of causality connections within EU countries. The insurgence during the crisis periods of causality relations between countries which were not connected before crisis periods is assumed to be an evidence of contagion. Moreover, this methodology allows to detect the *versus* of these connections and, consequently, to examine how shocks are transmitted through markets.

We implement the Granger-causality test in addition to the cointegration analysis performed in the previous step (§ 3.1) because it allows us to investigate also the short-run relations among countries, while the cointegration test mostly detects the log-run equilibrium relationships[14].

This method establishes how much of the current value of *y* can be explained by its past values and then to see whether adding lagged values of *x* can get better the explanation. The conventional Granger test specifies a bivariate vector autoregressive (VAR) model with a lag length set as k:

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

13 As co-integration analysis aims to identify the number of long-run relations among time series, the time length chosen to run the test required to be not too short. We test different window sizes and the results do not change significantly.

14 In particular, by applying the two econometric techniques (co-integration and Granger causality tests) we can establish which country has a dominant role in the contagion process, in the sense that it is able to influence the others ("leading country"), and which country is the most vulnerable in the sense that it is the most reactive to other countries price innovations ("follower country").

$$X_t = \alpha_X + \sum_{i=1}^{k} \beta_{X,i} X_{t-i} + \sum_{i=1}^{k} \gamma_{X,i} Y_{t-i} + \varepsilon_{X,t}$$

$$Y_t = \alpha_Y + \sum_{i=1}^{k} \beta_{Y,i} Y_{t-i} + \sum_{i=1}^{k} \gamma_{Y,i} X_{t-i} + \varepsilon_{Y,t} \qquad (2)$$

The Granger causality is examined by testing whether all γ_i are equal to zero using a standard *F-test*. For example, if we cannot reject the null hypothesis in Eq. (2), *Y* is said to Granger-cause *X*. If causation cannot be rejected in both equations, the variables are interdependent.

The above equations are, however, only valid for series that are stationary – that is I(0). In earlier causality studies, time-series that were found to be non-stationary – that is I(1) – were differenced and thus converted into stationary series on which the Granger causality tests could be applied[15]:

$$\Delta X_t = \alpha_X + \sum_{i=1}^{k} \beta_{X,i} \Delta X_{t-i} + \sum_{i=1}^{k} \gamma_{X,i} \Delta Y_{t-i} + \varepsilon_{X,t}$$

$$\Delta Y_t = \alpha_Y + \sum_{i=1}^{k} \beta_{Y,i} \Delta Y_{t-i} + \sum_{i=1}^{k} \gamma_{Y,i} \Delta X_{t-i} + \varepsilon_{Y,t} \qquad (3)$$

Later research, however, showed that this procedure is only correct if the two series are not co-integrated (MacDonald and Kearney, 1987). For co-integrated series, different approaches to causality testing have to be applied. Based on results of Sims et al. (1990), Demetriades and Hussein (1996) argue that test statistics derived from a level VAR framework are not valid unless the variables employed are either I(0) or I(1) and co-integrated. This implies that Eqs. (2) and (3) could be used to test Granger-causality for not co-integrated series. On the other hand, Engle and Granger (1987) and Granger (1988) argue that in the presence of cointegration, causality tests, which ignore the error correction term (ECT) derived from the cointegration relationship are misspecified and suggest to re-parameterize the model in the equivalent error correction model form (VECM). The causality tests in this case are based on the following equations:

$$\Delta X_t = \alpha_X + \sum_{i=1}^{k} \beta_{X,i} \Delta X_{t-i} + \sum_{i=1}^{k} \gamma_{X,i} \Delta Y_{t-i} + \varphi_X ECT_{X,t-1} + \varepsilon_{X,t}$$

$$\Delta Y_t = \alpha_Y + \sum_{i=1}^{k} \beta_{Y,i} \Delta Y_{t-i} + \sum_{i=1}^{k} \gamma_{Y,i} \Delta X_{t-i} + \varphi_Y ECT_{Y,t-1} + \varepsilon_{Y,t} \qquad (4)$$

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 γ_i provides evidence regarding a short-term adjustment dynamics. The *t-test* of the estimated coefficient φ 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. In this step, as already stated, we are interested in the creation of new short-run relations among countries as evidence of contagion (γ_i).

15 There is also the possibility that one variable is found to be I(0) and the other I(1). In these cases, the I(1) variable will be included in the equation in terms of first differences whereas the I(0) variable will be included in levels. As the first differences of an I(1) series will be I(0), this procedure ensures that all series included in the equation are I(0).

Taking these considerations into account, we proceed as follows: first, we test the time series for unit roots followed by tests for cointegration among any pairs of countries by applying standard Durbin-Watson (DW) and Dickey-Fuller (DF) tests. If the series are found to be I(0), causality testing according to Eqs. (2) will be applied. If the series are found to be I(1) and not co-integrated, causality testing according to Eqs. (3) will be applied. If the series are found to be I(1) and co-integrated, causality will be tested based on Eqs. (4) .

The estimation is conducted separately for all sub-periods (the so-called "*contagion windows*") identified in the first step (§3.1) on sovereign spreads and stock returns. The lag length *k* is chosen in order to generate a white noise error term ε_t. Investigating the presence of a unit root in the model requires to study basic information criteria given by Akaike information criterion (AIC), Schwartz criterion (SC) and Hannan-Quinn criterion (HQ).

Another result that we obtain in this step is the direction of the long-run connections we detected among sample countries. If the series are co-integrated we can identify the direction through which adjustment is applied, i.e. who is the leader and who is the follower in the contagion transmission, by applying the Gonzalo-Granger statistic in the context of a bivariate cointegration analysis (Engle and Granger, 1987).

To make clear how does this statistic works, let's assume that we have two countries only. As we have already stated in the previous sub-section (§ 3.1), the long-run coefficients matrix Π in equation (1) can be expressed as $\Pi = \alpha\beta'$, where α measures the speed of convergence to the log-run equilibrium of the two hypothesized countries, while β contains the parameters of the common stochastic trend.

If the parameter of the speed adjustment of the first country (α_1) is statistically not significant, whilst the parameter of the speed adjustment of the second country (α_2) is positive and significant, this indicates that the adjustment process towards the long-term relationship is determined by changes to the variable of the second country in response to changes of the variable of the first country, namely that the leading role in the contagion transmission is played by the first country. If, instead, α_1 is negative and statistically significant, whilst α_2 is not significant, it is the second country that plays the leading role. When both parameters are significant (and in that case we have an alternation of sign), both country contribute to the contagion transmission process and the Gonzalo-Granger statistic, defined as $\frac{\alpha_2}{(\alpha_2-\alpha_1)}$, allows us to establish which country makes the greatest contribution to the contagion transmission process[16].

16 If the result in absolute value exceeds 0.5, the price of the first asset plays a more important role compared to the price of the second asset, whilst if it is lower than 0.5 (the maximum for construction is 1), the opposite is true.

3.3 Variance decomposition

The last contagion indicator that we use 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 usual 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 conceptual framework previously discussed, we assume that contagion occurs every time the degree of vulnerability of one country – measured as the fraction of his 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[17].

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:

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

where *N* is the number of countries included in the sample.

As a consequence, for each country stock market *i* the ratio

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

17 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, ...T.

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- $W_i(i)$) 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.

4 Results

4.1 Identification of contagion windows

Our analysis begins by examining how the 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 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 crisis analyzed (Lehman's default and sovereign-debt crises).

In particular, in this section we apply a dynamic bivariate cointegration analysis (the first of our three-steps procedures, illustrated in section §3.1) detecting long-run relationships, which are connections among markets that lead to slow price adjustment processes.

The window size of our rolling indicator is 1.000 days and we take into consideration daily change of sovereign spreads and stock index returns, because we have verified that sovereign spread and log-price are not stationary in levels.

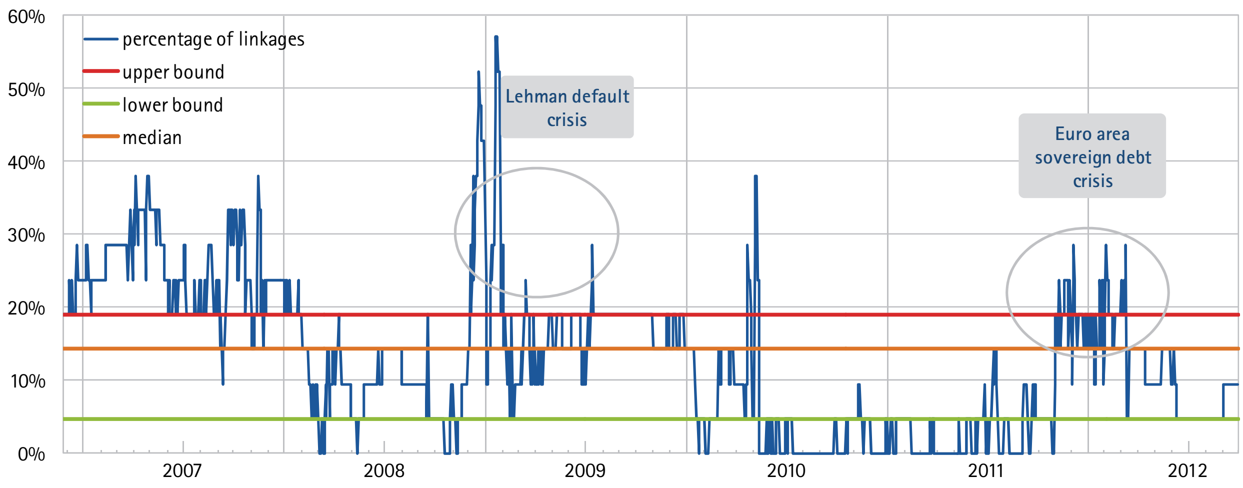
The empirical distribution of the percentage of relevant connections is used to identify contagion windows. If our indicator exceeds the III° quartile (upper bound), the percentage of relevant connections can be considered significantly high and the period is considered as turbulent, while the benchmark "tranquil" period is identified by the I° quartile (lower bound). Indeed, if the indicator is under the I° quartile, the number of connections can be considered significantly low. As a consequence, we identify "crisis" ("tranquil") windows by detecting periods during which for an high percentage of times the indicator is above (under) the upper (lower) bound.

In Figure 1, we plot the mentioned indicator and its bounds applying the methodology described in §3.1 to sovereign spreads. The indicator has been quite stably 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 from December 2008 to July 2009. In fact, during this period, which lasts 162 days, in 24 per cent of the cases the indicator of the percentage of connections is above the III° quartile, and in 81 per cent of the cases it is above or equal to the median. The "tranquil" window goes from April 2008 to November 2008, that is a period of time during which in 73 per cent of the cases the indicator is strictly under the median and in 36 per cent 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 per cent of the cases the indicator is above or equal to the median and, in particular, in 14 per cent 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.

Figure 1 – Contagion windows estimation using sovereign spreads

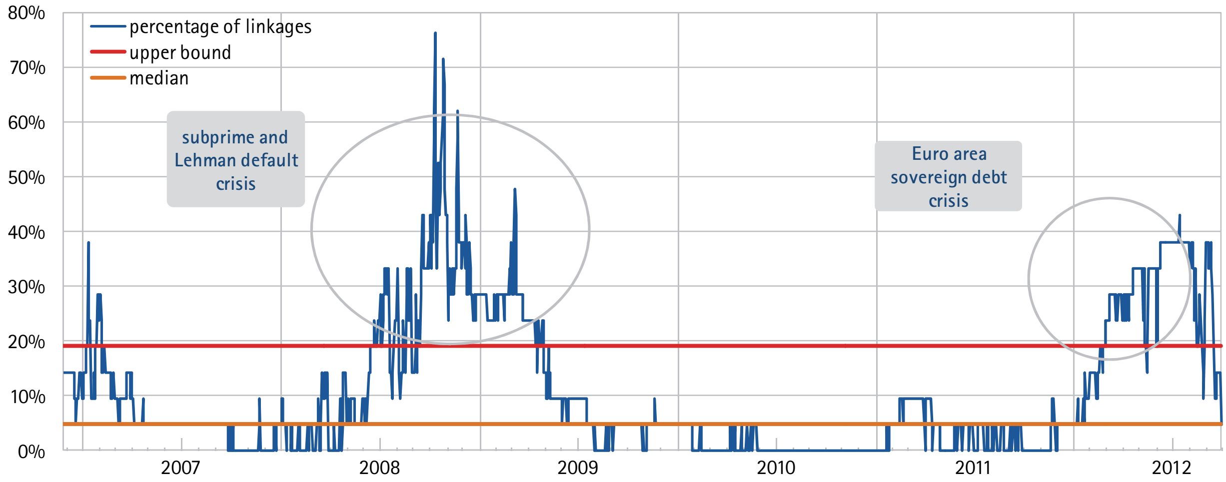


In similar way we identify contagion windows using stock returns, though in this case the lower bound is equal to zero (Figure 2).

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 per cent of the cases the indicator of connections is above or equal to the median and, in particular, in 54 per cent of the cases it is strictly above the upper bound), while the benchmark "tranquil" period goes from October 2006 to February 2008 (when the indicator is almost 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.

Figure 2 - Contagion windows estimation using stock returns



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.

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

Sovereign spreads contagion indicator reaches a peak at the end of 2008, that is with some delay respect to the Lehman default. In this case, over 30 per cent 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 per cent). Thereafter, the indicator is quite volatile till 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 levels. 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 approximately in March 2008 and ends around July 2009 and includes, consequently, both the subprime and the Lehman default crisis; in September 2008 more than 50 per cent 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 has not overcome 40 per cent.

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 has led the increase of correlation among stock markets.

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 verify if the number of significant connections in the "crisis" period grows compared to the "tranquil" period. Indeed, till now we have considered only long-run connections which imply 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.

Table 1 – Characteristics of the contagion windows

	Lehman default crisis	Euro area sovereign debt crisis
Sovereign spreads	<u>01/12/2008 - 14/07/2009</u>; 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.	<u>02/11/2011 - 05/06/2012</u>; 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	<u>10/03/2008 – 16/07/2009</u>; 354 days; in 88% of the cases the indicator is above or equal the median; in 52% if the cases the indicator is strictly above the upper bound.	<u>09/01/2012 - 28/09/2012</u>; 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.

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. We apply both the bi-variate Johansen cointegration test and the Granger causality test (see §3.2). The bi-variate cointegration test, indeed, allows us to identify connections between couple of markets which lead to slow price adjustment processes (*long-run* connections). Not only we detect links, but we also find the *versus* 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*) (see Appendix for econometric details).

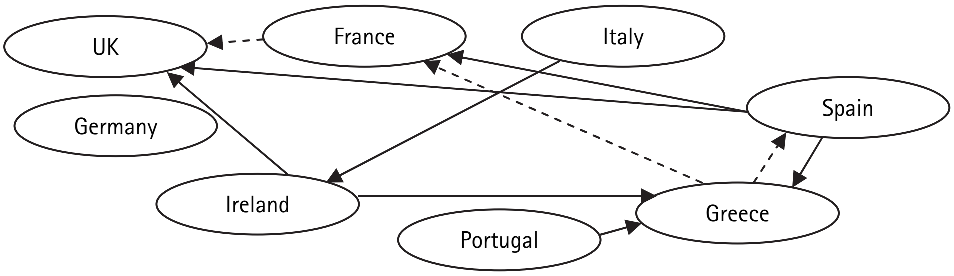
As a result, both techniques (bi-variate cointegration test/Gonzalo Granger statistic and Granger causality test), allow to identify significant cross-market connections and the direction of these relations. Thereafter, by applying the two tests we can establish which countries have a dominant role in 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 bi-variate 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 we report the value of the test statistic and its significance level (Table 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).

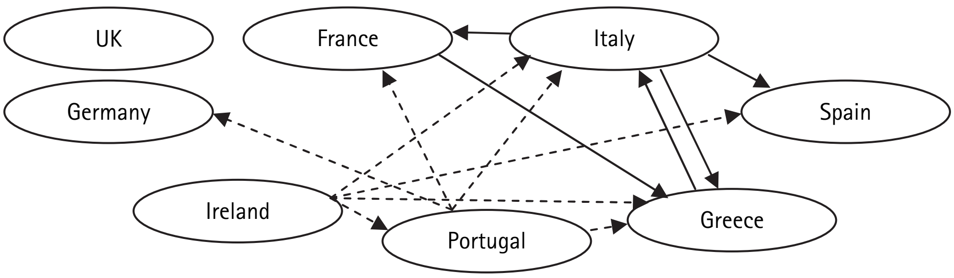
The representation that we have chosen allows us to go through the structure of the contagion transmission mechanism (Figure 4 and Table A.1 refer to sovereign spreads). During the sovereign debt crisis (November 2011 – May 2012), Germany and Spain have a dominant role in the contagion process, because 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, respect to 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 lost their leading role in 2011-2012. Lastly, Italy becomes a pure follower country in the sense that it absorbs shocks without being able to influence other countries signaling a high degree of vulnerability.

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

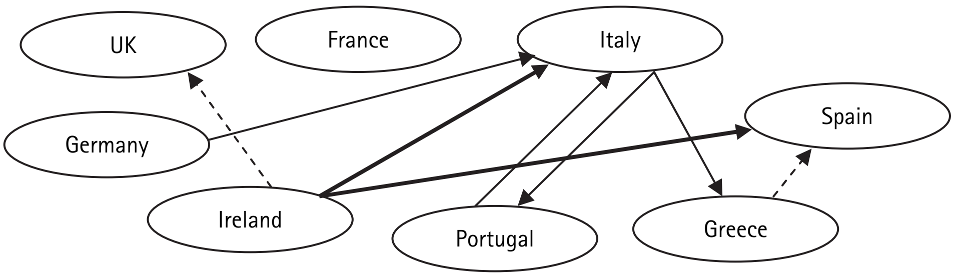
"TRANQUIL PERIOD": APRIL 2008 – NOVEMBER 2008



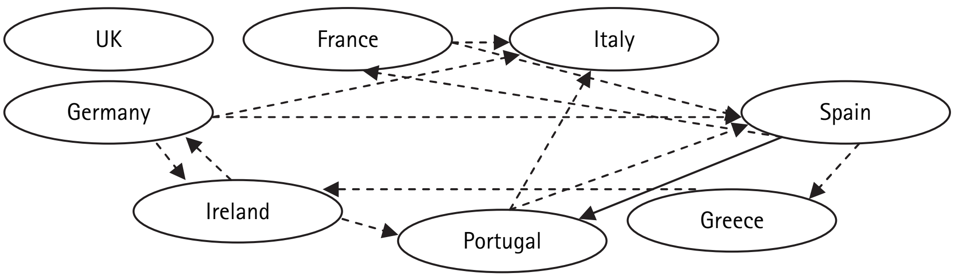
LEHMAN DEFAULT CRISES: DECEMBER 2008 – JULY 2009



"TRANQUIL PERIOD": MAY 2010 – DECEMBER 2010



SOVEREIGN DEBT CRISES: NOVEMBER 2011 – MAY 2012



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

One difference between the two crises considered (Lehman default crisis and sovereign debt crisis) that clearly emerges, concerns the overwhelming weight of short-run connections during the most recent sovereign debt crises (12 short-run links over 13 total links detected) compared to the Lehman default crises (8 short-run links over 13 total links). Moreover, it seems that "crisis" periods (both Lehman and sovereign debt crisis) are characterized by a substantial increase in the number of short-run links compared to the "tranquil" periods, which, on the contrary, show a prevalence of long-run connections (7 log-run links over 10 total links during the "pre Lehman tranquil period" and 6 log-run links over 8 total links detected before the sovereign debt crises).

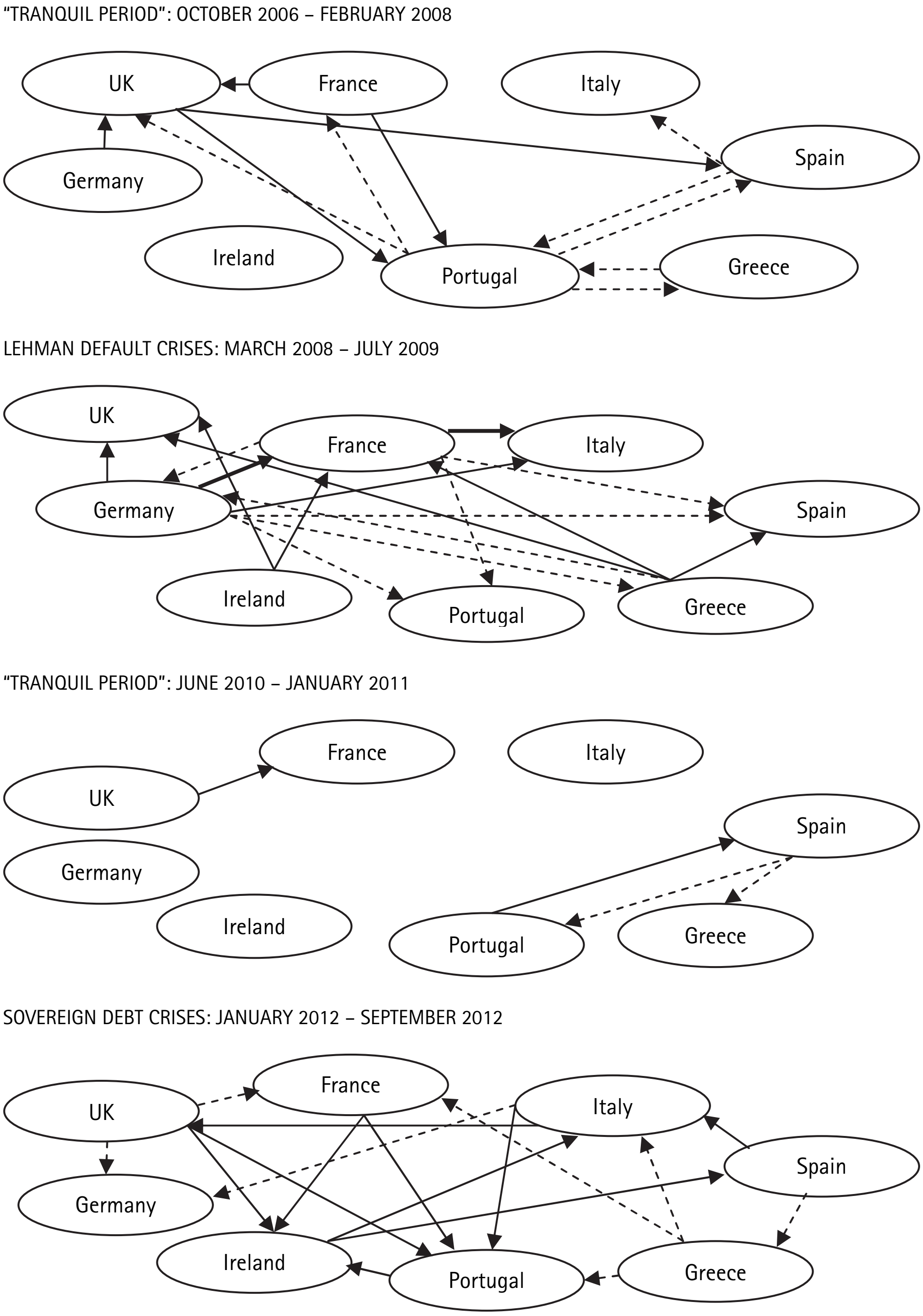
The procedure applied on stock returns is analogous to the one just described for sovereign spread time series. In Figure 5 we represent all the relations (short and long-run) using stock returns and the direction of these connections shed light on the structure of the contagion propagation mechanism; 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 *versus* 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 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 had 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 crises is significantly connected with Spain, Greece, Portugal and Ireland (January 2012 –September 2012).

Lastly, during the sovereign debt crisis, Italy, Greece and UK have a dominant role in the contagion transmission mechanism and the number of relevant connections which involve Portugal and Ireland is higher compared to what has been observed in 2008-2009.

As a result, the evidences of contagion using stock returns have a quite 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.

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



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

One important feature of our results which confirms the existence of *contagion* as opposite to *interdependence* is that the number of connections detected among countries (in either sovereign bond and stock markets) increases after the "crisis episodes" but do not stabilize at such higher level 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 feature is a critical test to distinguish between *contagion* and *interdependence*, since contagion is a significant increase in the co-movement between assets during a period of crisis, compared with a tranquil period. Therefore, if there is a high level of market co-movement in all periods, it is the case for *interdependence*. As regards to the European countries analyzed in our paper, a higher number of connections which don't held steady after a shock – but returns to low values once the crises is 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 Involvement in the contagion process

Our last step is given by 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 §3.3). 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 per cent to 8 per cent for Germany and from 4 to 16 per cent 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%)[18]. As regards to Lehman default crises, Greece, Italy and Portugal are countries that record the most severe worsening of external fragility, in contrast to Germany, which was essentially unaffected[19].

18 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%).

19 The rates 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 2 – Rate of involvement in 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.

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 crises increases significantly compared to what has been observed during the Lehman default crisis, given that the ratio of the forecast error variance explained by foreign market innovations has increased from 7 to 12 per cent. The degree of exposition of France has, instead, decreased from 7 to 2 per cent. Therefore, even using this methodology, the role of peripheral countries in the contagion process during the sovereign debt crisis have been more relevant compared to the "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%).

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 5 days forecast horizon.

As regard to 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 countries more exposed to financial contagion due to their highest degree of fragility (about 12%, 7% and 6%), while Germany and Ireland record the worse performance in term of rise of 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 main results obtained in sections 4.1, 4.2. and 4.3 using 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, an 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 rate of involvement of Portugal in the contagion process, in which Greece has clearly a dominant role as leading country.

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

6 Conclusions

The recent financial crisis, 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 the 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*.

One of the main interest of contagion studies is connected to the very basic principle of international portfolio diversification, the rationale being that international diversification should theoretically significantly reduce portfolio risk, but when cross-country correlations increase during crises, much of this rationale is undermined. Developing an understating of financial contagion would clearly be beneficial for policy makers hoping to manage and avoid future spreads of crises.

In this paper we apply a three step 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. The novelty of the paper is the fact that we contemporaneously take into consideration stock markets and sovereign bonds markets.

Results highlight the fact that there has been contagion both during Lehman crisis and sovereign debt crisis, given that the number of cross-market connections has significantly increased after such crisis episodes and then has newly reduced (at least for the Lehman episode). In particular, if we compare the timings of contagion for the two assets, we find that during the sovereign debt crisis (2011-2012) contagion in sovereign debt markets has led the increase of correlation among stock markets, while during the Lehman default crisis (2008-2009) financial contagion in stock markets has emerged before the contagion in sovereign spreads.

As regards to the equity market, results highlight that while after the Lehman default, the most contagion pulse over stock returns has been transmitted by «core» countries as Germany and France, during the sovereign debt crisis the contagion phenomenon hit predominantly the peripherals countries as Italy, Greece and Portugal.

As regards to sovereign spreads, peripherals 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. Lastly, 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 link to the others and, in turn, reveals to be affected by the most large number of contagion links coming from other economies. Moreover, Italy turns out to be more closely connected with peripheral countries during the Lehman default crisis and more with the «core» countries (as Germany and France) during the last recent sovereign debt crisis.

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Appendix

Granger causality methodology

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[1]:

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

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, Uk* and *N* is the number of countries included in the sample (*N=8*). If the time series are not co-integrated, $\alpha_k \beta'$ is equal to zero and the model becomes a VAR(p)[2]. 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 $\gamma_{i,j}$ for *i=1,..,p* is significantly different from zero, this means that $\Delta spread^j$ influence $\Delta spread^k$.

The Granger causality test for the stock markets allows 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:

$$R_t^k = \nu_0 + \sum_{i=1}^{p} \vartheta_i^{Usa} R_{t-1-i}^{Usa} + \sum_{j=1}^{N}\sum_{i=1}^{p} \nu_{i,j} R_{t-i}^j + \alpha_k \beta' \begin{bmatrix} \log(P_{t-2}^{Usa}) \\ \log(P_{t-1}^{Uk}) \\ \log(P_{t-1}^{Germany}) \\ \log(P_{t-1}^{France}) \\ \log(P_{t-1}^{Italy}) \\ \log(P_{t-1}^{Spain}) \\ \log(P_{t-1}^{Greece}) \\ \log(P_{t-1}^{Portugal}) \\ \log(P_{t-1}^{Ireland}) \end{bmatrix}$$

1 We have verified that the spread is not stationary in the levels on the basis of the Augmented Dickey Fuller test.

2 The order p of the model is based on the application of the HQIC and SBIC information criteria.

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). Given that the Us stock index return is included in the model, we have to take into consideration the synchronization issue[3]. Indeed, the Us stock market operates in a different time zone respect to the European countries and is characterized by different opening and closing times. In particular, activities in the Us stock market today impact the European one 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 $\nu_{i,j}$ for *i=1,..,p* is significantly different from zero, this means that R^j influences R^k .

3 We remember that in the case of sovereign spread application we take into consideration the US stock market implicitly as the benchmark respect to which the spread is computed.

Connections among sovereign bond markets

Table A.1 – Significant connections among sovereign spread markets

APRIL 2008 – NOVEMBER 2008 – "TRANQUIL" PERIOD OF TIME

leading country / *follower country*	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	-	-	-	-	-	-	1.1**	-	-	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

leading country / *follower country*	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	-	-	-	-	-	-	-	-	-	-	-	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**	-	10.0***	-	-	*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

leading country / *follower country*	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	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*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*

--- cont. ---

--- Table A.1 cont. ---

NOVEMBER 2011 – MAY 2012 - EURO AREA SOVEREIGN DEBT CRISIS

leading country / *follower country*	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	-	-	-	-	-	-	-	-	-	-	-	-	-	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). 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. 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.

Connections among stock markets

Table A.2 – Significant connections among stock markets

OCTOBER 2006 – MARCH 2008– "TRANQUIL" PERIOD OF TIME

leading country / follower country	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 country / follower country	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**	-	-	-	-	-	8.3***	-	-	-	-	-	-	*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 country / follower country	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*

--- cont. ---

--- Table A.2 cont. ---

JANUARY 2012 – SEPTEMBER 2012- SOVEREIGN DEBT CRISIS

leading country / *follower country*	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	-	-	-	-	-	-	2.6**	-	-	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). 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. 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.