Kalbaska A., Gatkowski M., "Eurozone Sovereign Contagion: Evidence From the CDS Market (2005-2010)", Journal of Economic Behavior & Organization, special issue: "Financial instability and contagion", accepted for publication, 2012

Eurozone Sovereign Contagion: Evidence From the CDS Market (2005-2010)

Kalbaska A.[a,†], **Gątkowski M.**[b,*]

[a] University of Siena, Department of Economics, 7 S. Francesco Sq, Siena, 53100, Italy.

[b] University of Essex, Centre for Computational Finance and Economic Agents, Wivenhoe Park, Colchester, CO4 3SQ, United Kingdom .

Abstract

This paper analyses the dynamics of the credit default swap (CDS) market of PIIGS, France, Germany and the UK for the period of 2005-2010. The study is performed on the basis of the Datastream and DTCC data on CDS spreads and the BIS data on cross-border exposures. The analysis of the data shows that sovereign risk mainly concentrates in the EU countries. The EWMA correlation analysis and the Granger-causality test demonstrate that there was contagion effect since correlations and cross-county interdependencies increased already after August 2007. Furthermore, the IRF analysis shows that among PIIGS the CDS markets of Spain and Ireland have the biggest impact on the European CDS market, whereas the CDS market of the UK does not cause a big distress in the Eurozone. The adjusted correlation analysis confirms that Greece and other PIIGS (even Spain and Italy) have lower capacity to trigger contagion than core EU countries. Besides, Portugal is the most vulnerable country in the sample, whereas the UK is the most immune to shocks.

Keywords: credit default swaps, sovereign risk, contagion, PIIGS, Eurozone

JEL Classification: E44, F34, G01, G15, H63

Highlights:

- Sovereign risk mainly concentrates in the EU countries
- France, Germany and the UK are heavily exposed to PIIGS
- The global financial crisis triggered the sovereign debt crisis
- PIIGS have lower capacity to trigger contagion than core EU countries
- Portugal is the most vulnerable, whereas the UK is the most immune to shocks

We thank Prof. Alessandro Vercelli from University of Siena and Prof. Sheri Markose from University of Essex for their supervision; Dr.Simone Giansante and Ali Rais Shaghaghi for interesting remarks and useful discussions. We are grateful to participants of the conference 'Can it Happen Again?' at the University of Macerata, Italy (October 2, 2010). We also thank the anonymous referee for the valuable comments and suggestions. As usual all remaining errors are ours.

† Email address: kalbaska@unisi.it.

* Corresponding author, email address: mgatko@essex.ac.uk.

Eurozone Sovereign Contagion: Evidence from the CDS market (2005-2010)

1. Introduction

The global financial crisis of 2007-2009 led to the demise of several global banks and institutions. Some of the banks that were "protagonists" of the crisis were so called "too big and too interconnected to fail". Therefore, states all over the world "sponsored" them by taking on the risk in the banking system and for a year they contained it. Yet, insolvencies that marked the crisis were passed on to sovereign states because of their excessive debt issue to save the financial industry. Thus, the global financial crisis has grown into a full sovereign debt crisis.

In 2010 the Eurozone became strongly distressed by the series of events starting with the problems of Greece being unable to repay its debt and eventually being bailed out by the EU and the IMF. Greek problems fostered the fear about the fate of other European economies, especially heavily indebted countries such as Portugal, Ireland, Italy and Spain that along with Greece are usually referred to as PIIGS. Eventually, the EU and the IMF agreed on the bailout packages for Ireland and Portugal and one more bailout package for Greece. However, these bailouts do not make the risk disappear. They simply transfer the risk to the governments and taxpayers of other European countries. Thus, the current sovereign debt crisis for the first time seriously tests the Eurozone since its start in 1999.

Our study focuses on the credit default swap (CDS) market of PIIGS along with so called "core" countries such as France, Germany and the UK since they bought a large share of the debt of PIIGS. CDS spreads are a good data source to test for contagion as they can serve as a proxy for the default probability of a counterparty on which a CDS contract is written. Observing co-movements of CDS spreads of different countries can help to understand how the market estimates correlations of their default probabilities and also the direction of future defaults.

The major studies on the sovereign CDS market were performed by Longstaff et al. (2011) and Pan and Singleton (2008), however, they were not focused on the Eurozone countries. Recently, as a result of the rapidly worsening situation in the Eurozone the focus has changed dramatically and a number of empirical papers have addressed the issues of the sovereign risk in the Euro area. We touch upon a few contributions made by Alter and Schuler (2011), Aizenman et al. (2011), Acharya et al. (2011), Dieckmann and Plank (2011), Delatte et al. (2011), Fontana and Scheicher (2010), Ejsing and Lemke (2009).

One strand of the recent empirical literature focuses on the joint dynamics between the sovereign and bank CDS market. Thus, Alter and Schuler (2011) study the relationship between the sovereign CDS of seven EU countries and the CDS of their banks. The authors analyse the period between June 2007 and May 2010 and look at differences in the market before and after government interventions.

They find that before the government rescue interventions contagion spills over from the banking sector to the sovereign CDS market, whereas after the interventions sovereign CDS spreads largely determine the price of banks' CDS series. The authors also highlight the short-term impact of the financial sector on sovereign CDS spreads and its insignificance in the long run.

Dieckmann and Plank (2011) also find evidence for a private-to-public risk transfer in the countries with government interventions. Moreover, the authors argue that this transfer is larger for the European Monetary Union (EMU) countries that are more sensitive to the health of the financial system than non-EMU states.

Ejsing and Lemke (2009) examine co-movements between CDS spreads of ten Euro area countries and CDS of their banks for the period from January 2008 to June 2009. The authors find that the government rescue packages led to a decrease in the CDS spreads of the banking sector at the cost of the increase in the price of sovereign CDSs. Furthermore, the bailout schemes made sovereign CDSs even more sensitive to any future shocks. Likewise, Acharya et al. (2011) find empirical evidence for the direct two-way feedback between the banking and sovereign CDS market of the Eurozone countries for the period of 2007-2011.

Another strand of the recent empirical literature investigates the relationship between the sovereign CDS and bond market. Fontana and Scheicher (2010) identify the main determinants of the bond and CDS spreads of ten Euro area countries and explain which factors drive the differences in pricing between the two markets. The authors suggest that 'flight to liquidity' effects and limits to arbitrage may explain why CDS spreads exceed bond spreads. They also show that common factors are the main reason for the repricing of sovereign credit risk.

Similarly, Delatte et al. (2011) use a non-linear approach to analyse the influence of CDS premia on underlying bond spreads for PIIGS and five core European countries. The authors conclude that CDS spreads are a better indicator of the probability of default during the periods of turmoil.

Furthermore, there are studies that investigate the relationship between the sovereign CDS market and economic fundamentals. Thus, Aizenman et al. (2011) compare the market pricing of CDSs in the Eurozone (and PIIGS in particular) and the pricing of risk in the rest of the world. They find evidence that in 2010 CDSs of PIIGS are priced much higher than CDSs of other countries with similar fundamentals. As a possible interpretation the authors suggest negative expectations of the market about the future fundamentals of PIIGS and their exchange rate inflexibility.

Thus, the research to date has tended to focus either on interactions between the sovereign CDS market and the financial sector or on the joint dynamics between the CDS and bond markets. However, far too little attention has been paid to the discussion of contagion between sovereigns.

The aim of this study is to examine sovereign risk and the occurrence of financial contagion in Europe. In order to explain the long-term dynamics of the CDS market of PIIGS and core EU

countries we carried out our analysis on an extended time period spanning from August 2005, well before the global financial crisis, until September 2010. In the literature there is a considerable amount of ambiguity concerning the precise definition of contagion and how we should measure it. There exists no theoretical or empirical definition on which researchers agree. Broadly contagion can be referred to as the cross-country transmission of shocks or general cross-country spillover effects. However, in order to capture the phenomenon of contagion quantitatively we used a very restrictive definition suggested by the World Bank. It assumes that contagion occurs when cross-country correlations increase during "crisis times" relative to correlations during "tranquil times"[1].

This study contributes to the empirical literature in several ways. Firstly, we used the multiple sources of data. The Datastream, DTCC[2] and BIS[3] data analysis showed that investors protected themselves from the possible adverse effects that the current sovereign debt crisis can have on Germany, France and the UK. Thus, there may be a two-tier structure of contagion – problems that emerge on the peripheries of the European economy may create a distress at the core of the EU. The analysis of the data also confirmed that sovereign risk mainly concentrates in the European Union.

Secondly, we applied a wide array of quantitative methods that provide a more complete picture of the situation in the CDS market of the studied countries over long period of time. The EWMA analysis found that there were several waves of contagion and correlations increased already after the credit crunch in August 2007. Besides, it confirmed the role of the global financial crisis in triggering sovereign risk. Similarly, the Granger-causality test revealed that cross-country interdependencies increased after the global financial crisis as compared to the pre-crisis period. The adjusted correlation analysis confirmed 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 shocks.

The rest of the paper is organized as follows. Section 2 analyses the Datastream and DTCC data on credit default swaps and the BIS data on cross-border exposures. Section 3 describes the main techniques and discusses the empirical results of the econometric analysis of CDS spreads. The last section concludes.

2. Data Analysis

The Datastream data was gathered on five-year CDS contracts issued on the bonds of nine sovereigns: Portugal, Ireland, Italy, Greece, Spain (PIIGS), France, Germany, the UK and the U.S. A credit default swap is a bilateral financial instrument that allows lenders to pass on the risk that a

[1] http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTPROGRAMS/EXTMACROECO/0,,contentMDK:20889756~pagePK:64168182~piPK:64168060~theSitePK:477872,00.html.

[2] Data are weekly published on the DTCC (Depository Trust and Clearance Corporation) website.

[3] Data on the amount of bank exposures are taken from the Bank for International Settlements.

borrower will default. CDS spreads are quoted in basis points. Higher spreads indicate growing market expectations of a default on the underlying debt with a jump to a default spike at the time of the credit event.

The dataset under study spans from the period of August 2005 until September 2010. The first turmoil on credit derivatives markets took place in August 2007. The paths of CDS spreads since December 2007 are shown in Figure 1[4].

It is possible to identify four phases. Between December 2007 and September 2008 the CDS spreads of different countries were growing simultaneously, even though the range remained rather narrow. Between October 2008 and March 2009 the market was undergoing the consequences of the collapse of one of the largest American investment banks Lehman Brothers. CDS spreads widened considerably since the problems in the banking sector started spreading to sovereigns. Between April and September 2009 CDS spreads were narrowing in response to the taxpayer bailout that subsidized the risk. Nevertheless, bad debts of banks led to the rise of sovereign risk and since November 2009 CDS spreads were steadily growing again. In March 2010 they jumped to very high levels and the significant differentiation between countries could be observed.

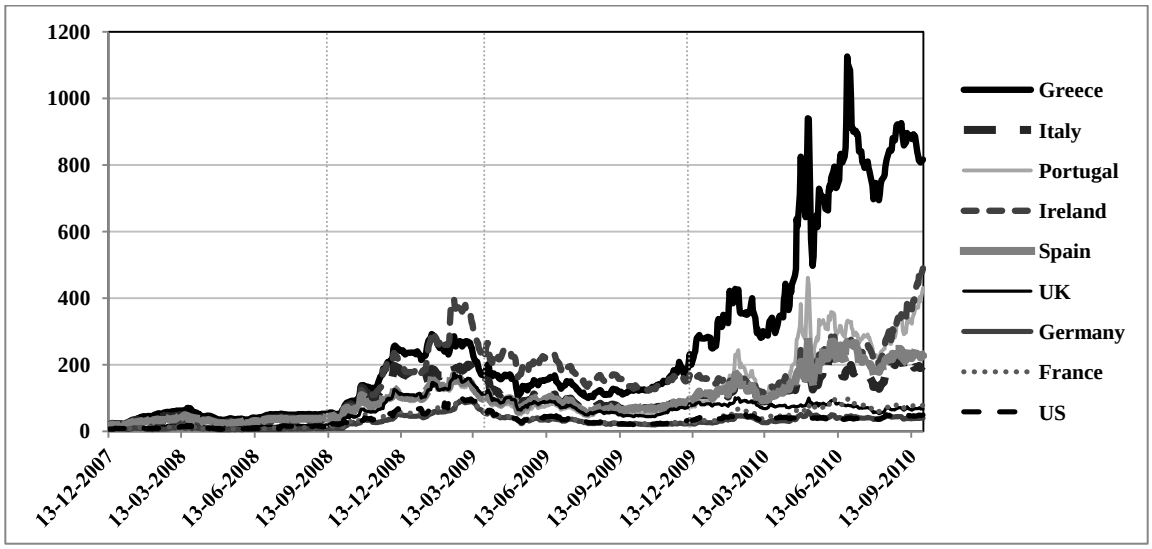

Figure 1. CDS spreads of PIIGS, France, Germany, the UK and the U.S. from December 2007. Source: Datastream

Figure 2 presents the movements of CDS spreads for PIIGS and core EU economies along with the U.S. from March to September 2010. Investigating the development of CDS spreads as the Eurozone sovereign crisis unfolded we clearly see that at the moment of the crisis investors were uncertain about the ability of Greece to repay its debt and the Greek CDS spreads surged in April 2010. However, investors continued valuing the riskiness of the Greek debt at high level even after its first bailout in May 2010 since the price of the Greek CDSs started growing again and peaked at

[4] The Datastream data for all sovereigns are available from December 2007.

the end of June 2010. The pattern of the Italian, Spanish, Portuguese and Irish CDS spreads is similar to that of the Greek, but the amplitude of movements is smaller. Moreover, since August 2010 with the Irish debt becoming more and more at risk we can see a clear rising trend in the Irish and Portuguese CDS markets.

For core European countries the behavior of CDS spreads was not uniform. Thus, for Germany spreads returned to the previous values, for France they doubled, whereas the price of the UK CDS spreads considerably dropped. This may suggest that investors did not worry about the influence of the Greek problems on Germany and the UK, whereas they seemed to anticipate some negative changes in France because of the turmoil in PIIGS. At the same time, for the U.S. we do not observe any major changes.

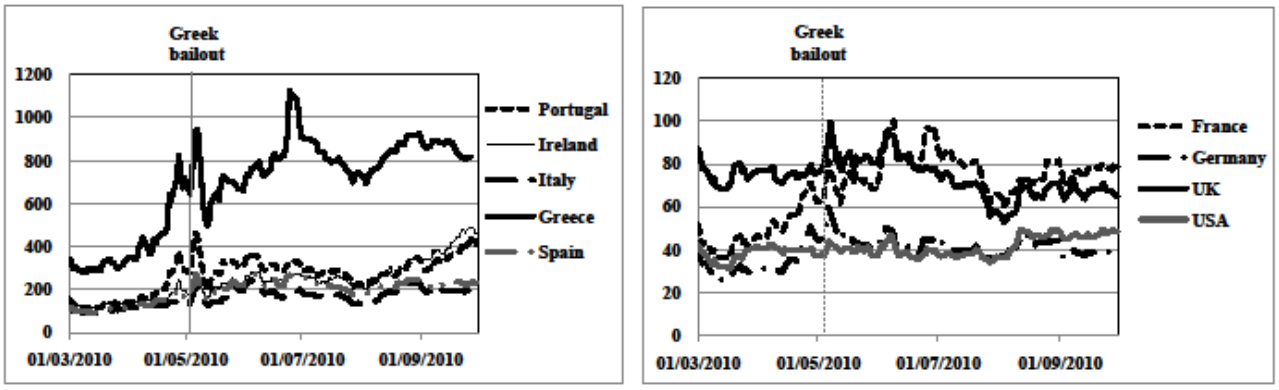

Figure 2. CDS spreads of PIIGS (left) and core EU countries and the U.S. for March-September 2010. Source: Datastream

Figure 3 presents the sum of the net notional (NetN) positions of banks that hold CDSs on the underlying sovereign debt from March to September 2010. This is the sum of the net protection bought by net buyers (or equivalently sold by net sellers). When NetN values grow it means that the positions of the market players are more unbalanced and investors increase their exposure to the CDS market. On the contrary, falling NetN values indicate that investors try to hedge more their positions.

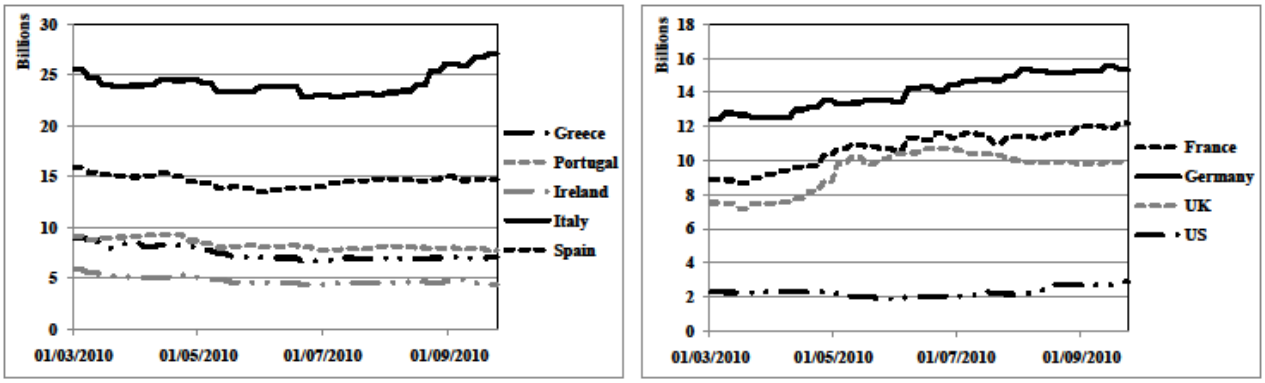

Figure 3. Net notional of CDS contracts of PIIGS (left) and core EU countries and the U.S. (right) for March-September 2010. Source: DTCC

For Greece, Portugal and Ireland the NetN fell after the first bailout decision in May 2010 by 16%, 15% and 13% correspondingly, whereas for Italy and Spain it first fell and then started increasing again. For France, Germany and the UK we see a clear growing trend for the NetN which ranged between 23% and 33%, whereas for the U.S. again there were no considerable changes.

The gross notional (GrossN) value of CDS contracts informs about the size of the market. It is the sum of all CDS contracts bought (or sold). The GrossN rose for all PIIGS with the largest value recorded on Italy and Spain and the smallest on Ireland and Portugal. The GrossN for core EU economies grew much stronger with the largest value recorded on Germany and France. The GrossN for the American CDS market almost did not change.

Thus, it can be observed that the problems of Greece triggered a surge in the CDS market activity of almost all of the countries under analysis. However, there are some differences between PIIGS, core European countries and the U.S.

Firstly, we can observe the withdrawal from the excessive exposure of PIIGS to one another since the net notional for these countries fell while the gross notional increased. This may suggest that the market players tried to hedge their open positions on the market by buying reverse contracts.

Secondly, investors buy/sell more protection on core EU players. Even though between March and September 2010 CDS spreads significantly increased only on France, there was a big market demand not only for the French CDS contracts, but also the German and the UK CDSs since investors wanted to insure the debt they hold. This led to an increase in the net notional along with a fairly strong rise in the gross notional value.

Thirdly, the American CDS market was not significantly affected by the Greek problems – there was no major increase in spreads and gross and net notional values as a result of the turmoil in Greece.

The BIS data on cross-border exposures show how much banking systems of different countries are exposed to PIIGS and the UK and thus may incur losses as a result of default of any of them. We use the data on an *ultimate risk basis* (i.e. contractual lending net of guarantees and collateral).

From figure 4 we see that PIIGS hold the debt of one another. However, it appears that the banking systems that are mostly exposed to them are those of France, Germany and the UK. For instance, the joint claims of only these three countries' banking systems on Greece, Ireland, Italy, Portugal and Spain constitute 69%, 60%, 71%, 43% and 62% of total claims of 24 reporting countries respectively[5]. We also see that almost all of the debt of PIIGS is held by the European banks. Its share ranges between 79% for Ireland and 95% for Portugal. The situation is slightly different for the UK where French and German banks hold smaller amounts of debt whereas the American banks

[5] The joint claims of French, German and British banks on Portugal are slightly lower than on other PIIGS since Spanish banks are highly exposed to Portugal and hold 42% of total claims on it.

holds 24% of total claims on the UK.

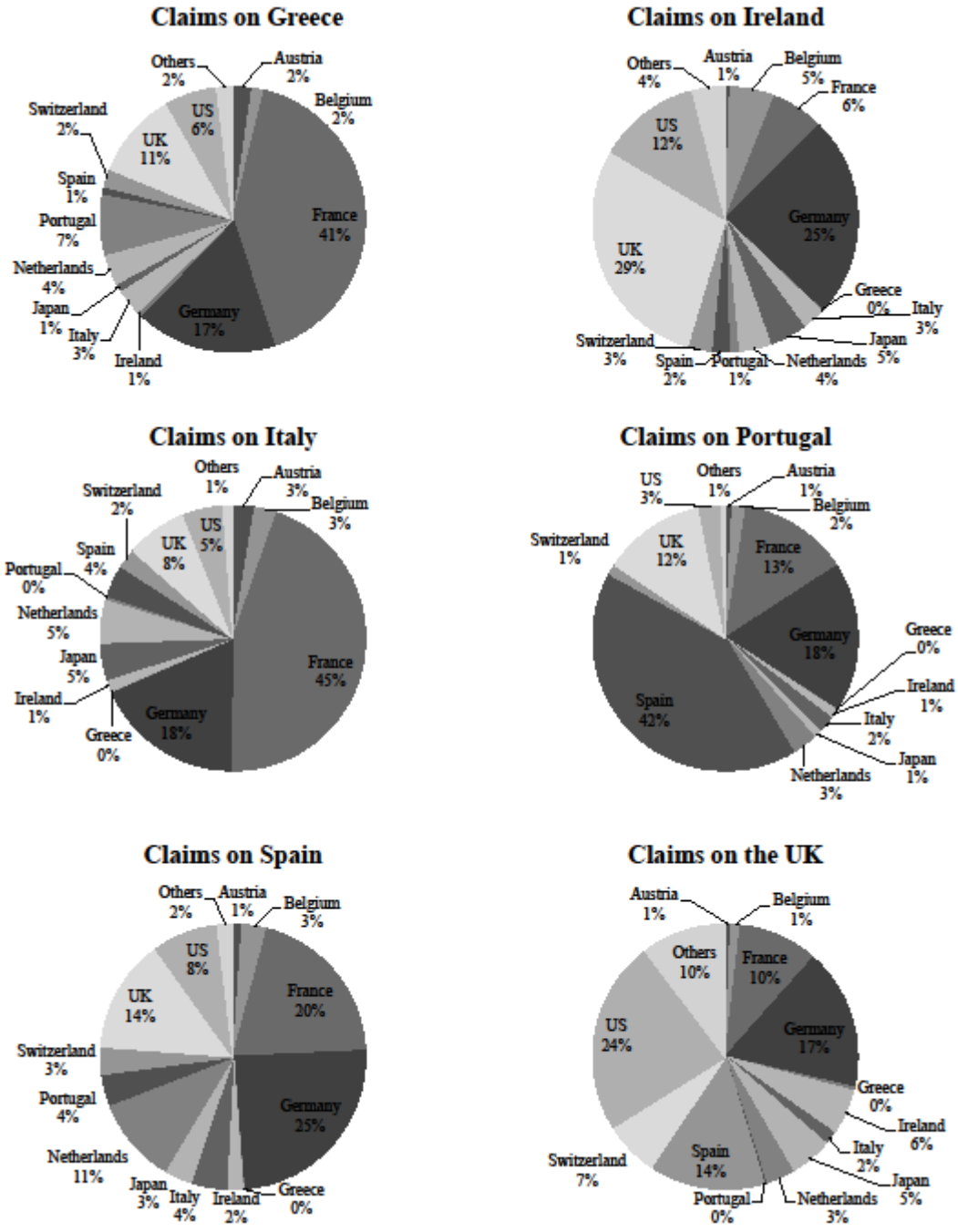

Figure 4. Cross-border banking sector exposures to PIIGS and the UK on the ultimate risk basis. Source: BIS, end March 2011

The exposure of the European banks to PIIGS has been growing since March 2005 for three consecutive years. After that, especially following the collapse of Lehman Brothers in September 2008 cross-border lending started decreasing. According to the BIS, at the beginning of 2010 for the first time since the Lehman Brothers collapse cross-border lending by banks rose again. Nevertheless, in the second quarter of 2010 it dropped considerably implying the outflow of capital from the European economies towards more stable regions.

The above findings suggest that the problems of Greece can trigger contagion that may affect not only other PIIGS but also core European countries since German, French and British banks are highly exposed to PIIGS. Thus, we may have a two tier structure of contagion – problems that emerge on the peripheries of the European economy may create a distress at the core of the EU.

Moreover, the current sovereign debt crisis seems to be entirely European since the exposure of American and other countries' banking systems to PIIGS is not particularly high. Besides, as we noticed before, the American CDS market did not significantly react to the problems of Greece. For this reason we excluded the U.S. from our further analysis.

3. Econometric Analysis of CDS Spreads

Since the data on CDS premia have a unit root we made them stationary by using log first differences.

$$x_t^i = \log(s_t^i) - \log(s_{t-1}^i) \qquad (1)$$

where s_t^i is the CDS spread of country i, i =1,…8 in period t and x_t^i represents log returns.

3.1. EWMA Correlations of CDS Spreads

We started our econometric analysis by estimating correlations of daily CDS spreads between countries. The analysis of correlations to test for contagion was employed by Caporale et al. (2005). Moreover, several studies (Lopez and Walter (2000), Ferreira and Lopez (2005)) suggested that models based on the Exponentially Weighted Moving Average (EWMA) perform quite well and can be used instead of other more complex methods. Furthermore, Gex and Coudert (2010) showed that there is very little difference between EWMA and DDC-GARCH (Dynamic Conditional Correlation GARCH) models.

The main idea of the EWMA is that the moving average is calculated by weighting components with an exponential factor. Recent values are of higher importance in the EWMA scheme. Thus, the further the data point is from the time for which the average is calculated the less influence it has on its value.

When the number of periods tends towards infinity the EWMA conditional correlations and EWMA variance can be expressed in the following autoregressive form:

$$\hat{p}_t^{ij} \approx (1 - \lambda)\frac{x_{t-1}^i x_{t-1}^j}{\hat{\sigma}_{t-1}^i \hat{\sigma}_{t-1}^j} + \lambda\, \hat{p}_{t-1}^{ij}, \qquad (2)$$

$$\hat{\sigma}_t^2 = (1 - \lambda)x_{t-1}^2 + \lambda\, \hat{\sigma}_{t-1}^2, \qquad (3)$$

where i is a triggering country; j is a given country in the sample; x_t^i and x_t^j are the log first

differences of CDS premia of country *i* and country *j*; λ is a parameter between 0 and 1; σ_t is the EWMA standard deviations of x_t.

Parameter λ is a key parameter in the EWMA scheme as it affects the decay of weights. The parameter should be such as to minimize the root mean square errors of forecasts. Estimation method for λ is suggested in RiskMetrics by JP Morgan[6].

In our case λ is equal to 0.939.

From figure 5 we can see that the lowest correlations were observed before the "credit crunch" that occurred in August 2007[7]. After the "credit crunch" correlations increased for almost all of the pairs. However, the European Central Bank saved the banks that were infected by the American "disease", and thus Europe survived the "credit crunch". Nevertheless, after the Lehman Brothers collapse in September 2008 correlations clearly spiked again. This could possibly be explained by the high costs of the financial sector bailout that transferred to sovereign risk.

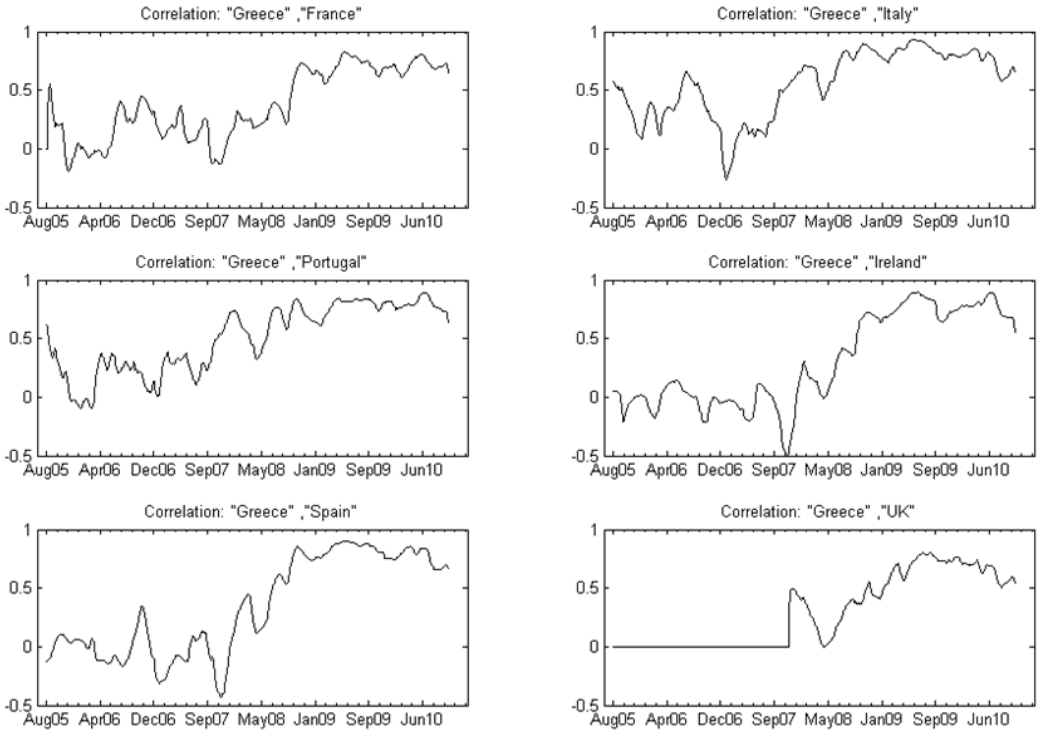

Figure 5. EWMA correlations between Greece and other sovereigns[8]

Since November 2009 when sovereign risk increased correlations between CDS markets grew further for most of the pairs. Table 1 shows that CDS markets of Portugal and Spain, Portugal and Ireland, Portugal and Italy, Italy and Ireland, Italy and Spain, Ireland and Spain were correlated the most, whereas correlations between CDSs of Greece and Germany, Greece and the UK, Ireland and

[6] J.P Morgan's result is λ =0.94.
[7] Since the data for the UK are available from November 2007 its correlation with Greece is shown as a straight line before this date.
[8] Charts for other sovereigns are available from the authors upon request.

Germany were the lowest. The analysis shows that the German CDS market was the most correlated with CDSs of France and the UK at the beginning of April 2010 when these core EU countries were taking a decision whether or not to bailout Greece. Besides, correlations between CDSs of Greece and Portugal, Italy and Ireland, Portugal and Ireland, Ireland and Spain, Ireland and Germany reached their maximum values after the bailout of Greece in May - June 2010.

Table 1. Average correlations between chosen countries for different periods

	Before credit crunch	**After credit crunch**	**After Lehman collapse**	**After sovereign risk increased**
	13.09.2006-12.09.2007	13.09.2007-12.09.2008	15.09.2008-30.10.2009	02.11.2009-29.09.2010
Greece-Italy	0.161	0.626	0.85	0.754
Greece-Portugal	0.219	0.573	0.767	0.791
Greece-Ireland	-0.057	0.077	0.749	0.761
Greece-Spain	-0.021	0.186	0.826	0.768
Greece-UK[9]	-	0.218	0.613	0.666
Greece-France	0.222	0.178	0.688	0.705
Greece-Germany	0.163	0.054	0.631	0.626
Italy-Portugal	0.401	0.736	0.841	0.857
Italy-Ireland	0.032	0.19	0.744	0.834
Italy-Spain	0.122	0.264	0.872	0.892
Portugal-Ireland	-0.011	0.239	0.737	0.823
Portugal-Spain	0.163	0.268	0.886	0.879
Ireland-Spain	0.092	0.559	0.771	0.834
Ireland-Germany	0.12	0.379	0.61	0.695
Spain-UK	-	0.237	0.638	0.754
Spain-Germany	0.065	0.31	0.658	0.728
UK-France	-	0.275	0.66	0.718
UK-Germany	-	0.233	0.542	0.706
France-Germany	0.502	0.358	0.718	0.791

In order to see whether there was contagion we have to verify whether correlations increased significantly during the crisis. We estimated regressions linking the EWMA conditional correlations (ρ_t) to their lagged values and different crisis dummy variables as in Gex and Coudert (2010) and Chiang et al. (2007):

$$\rho_t = \alpha_0 + \alpha_1 \rho_{t-1} + \alpha_2 D_t + \varepsilon_t \qquad (4),$$

where ε_t is normally distributed error term and D_t is a dummy variable for the specified crisis period (equal to 1 during the crisis and 0 before):

D_t^1 = 1 *after* 13.11.2007, D_t^1 = 0 *elsewhere*;

D_t^2 = 1 *after* 12.09.2008, D_t^2 = 0 *elsewhere*;

D_t^3 = 1 *after* 02.11.2009, D_t^3 = 0 *elsewhere*;

D_t^4 = 1 *after* 15.04.2010, D_t^4 = 0 *elsewhere*

[9] There are no values for the UK before the ‘‘credit crunch’’ since the data for the UK are available from 13.11.2007.

The first dummy represents a hypothesis that the crisis started after the "credit crunch" in August 2007[10]. The second dummy states that the crisis started after the Lehman Brothers collapse. The third dummy assumes that the crisis period started when sovereign risk increased in November 2009. The fourth dummy states that the crisis started shortly before the EU-IMF bailout of Greece in May 2010. Using various dummy variables allows us to identify which of the above periods is the most significantly represented as the crisis period in the data.

The R^2 coefficient for all regressions we estimated with OLS methods remains above 90%. The coefficient for the lagged endogenous variable is always significant and close to 1 – this corresponds to the high value of λ we used[11]. The most interesting result is the behavior of the dummy variables as their statistical significance confirms the contagion effect[12]. D_3 and D_4 are the most significant (in 10 and 12 out 28 experiments respectively) which assumed that the crisis started in November 2009 and when the problems of Greece worsened respectively. D_1 is significant only in six cases, whereas D_2 is significant in eight cases.

Taking into account 28 experiments pursued for each dummy variable we can draw a conclusion that there were several waves of contagion defined in terms of an increase in conditional correlations[13]. Firstly, the global financial crisis played its role in passing on the risk in the banking system to sovereigns, even though PIIGS and core EU countries survived the "credit crunch" and the default of the financial giants like Lehman Brothers. Secondly, the persistent transfer of the costs of the financial sector bailout to the sovereign risk led to the high debt and deficit in the Eurozone and thus created a new wave of contagion in November 2009. Thirdly, the further deteriorating situation in Greece in March - April 2010 made financial markets extremely nervous and finally led to the EU-IMF bailout first of Greece and later of Ireland and Portugal.

3.2. Granger-causality and Impulse Response Analysis

In order to identify a causal relationship and its strength between CDS markets of different countries we constructed a vector autoregression (VAR) model. We applied the Granger-causality test[14] and analysed impulse responses to see how long a shock introduced into the system may persist and which influence it has on the countries that are not directly affected by the shock. The analysis of VAR and Granger-causality to assess financial spillovers was applied by Galesi and Sgherri (2009), Gray (2009), Khalid and Kawai (2003) and Sander and Kleimeier (2003).

---

[10] Since we have data for all the sovereigns starting from 13.11.2007, we used this date as a starting point for D_t^1 .

[11] By definition of moving averages EWMA correlations are strongly autocorrelated.

[12] Regression results are available from the authors upon request.

[13] In our case correlations increased significantly by less than 1 %.

[14] The idea of Granger-causality is explained in Hamilton (1994).

One of the important issues in constructing a VAR model is a proper choice of the lag length. Some researchers choose it arbitrarily allowing just enough lags to ensure that the residuals are white noise but maintaining the precision of estimates. There are also some procedures that determine the appropriate lag length such as the Akaike information criteria (AIC), the Schwartz information criteria (SIC) and the likelihood ratio (LR) test. In our case the LR test is inconclusive, whereas the AIC and SIC tests find different optimal lag lengths to be employed. We think that just one lag suggested by the SIC test may not be enough to investigate the causal relationship over long periods. Therefore, we used the lag length suggested by the AIC test (three lags for the period before the crisis and six lags for the period after the crisis).

In order to see changes in the existence of causality between CDS markets of different sovereigns we investigated two periods: a pre-crisis period (August 18, 2005 – August 15, 2007)[15] and a crisis period (November 14, 2007 – September 29, 2010)[16].

Figure 6 presents the results of the Granger-causality test. In the pre-crisis period we identify 13 cross-country causations. There are three interesting findings here. Firstly, changes in the Greek CDS market cause changes in the CDS markets of other Southern European countries (ex. Portugal and Spain), whereas the CDSs of Greece are not Granger-caused by CDSs of any other country. It can thus be suggested that the Greek CDS market could be the source of the problems even before the crisis started. Secondly, the CDSs of Spain affect the CDSs of Portugal but with no reciprocal effect. Thirdly, in the pre-crisis period there is a significant interdependence between the CDS markets of France and Germany.

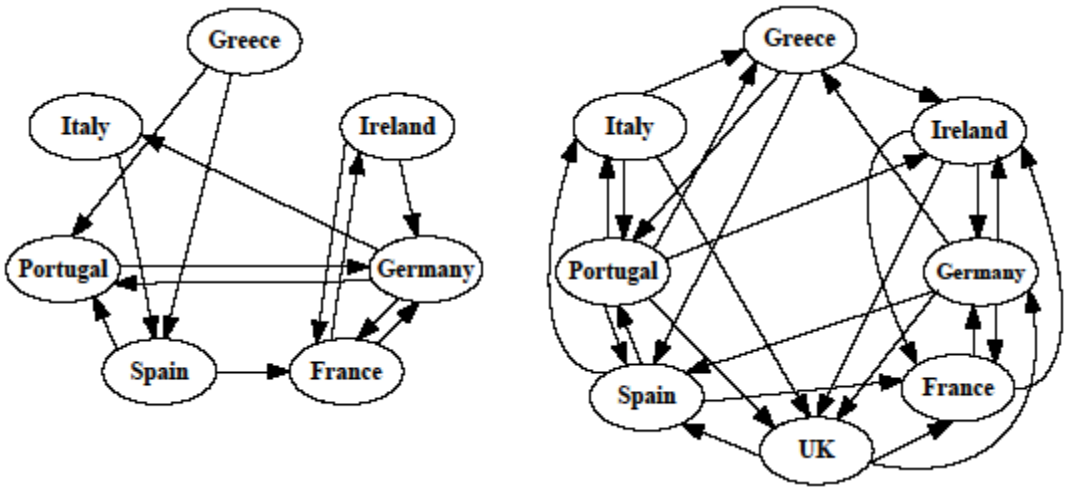

Figure 6. Granger-causality for the pre-crisis and crisis period

In the crisis period interdependencies between countries increased compared with the pre-crisis

[15] Since the data for the UK are available only for the period after November 2007 we did not perform the test on the UK for the pre-crisis period.

[16] To have a greater number of observations to determine causality we considered that the crisis period started after the credit crunch in August 2007 through the sovereign debt crisis.

period (27 statistically significant casual relationships). It is interesting to note that during the crisis changes in the CDS spreads of Greece affect not only the CDS markets of Portugal and Spain as in the pre-crisis period, but also the CDSs of Ireland. The CDS market of Ireland Granger-causes only the CDSs of core EU countries with no reciprocal effect. Unexpectedly, changes in the Irish CDSs do not cause changes in the CDS markets of other PIIGS and only CDSs of Portugal and Greece have a significant causal effect on the Irish CDS market.

What is surprising is that among PIIGS the Portuguese CDS market Granger-causes changes in the CDS spreads of all the countries in the sample apart from France and Germany. The CDS spreads of Spain cause changes in the Italian, Portuguese and French CDS spreads. Besides, in contrast to the pre-crisis period the test reveals Granger-causality between CDS spreads of Portugal and Spain in both directions in the crisis period (one-third of the Portuguese debt is held by Spain).

Among core EU countries the German CDS market exerts the highest impact and Granger-causes the CDSs of all the countries apart from Italy and Portugal. The CDS market of France affects only the CDSs of Ireland and Germany which along with Spain and the UK Granger-cause the French CDS market. The CDSs of the UK have a significant effect on the CDSs of Spain, France and Germany with the reciprocal effect of the German CDS market on the UK. The CDSs of the UK are also affected by some of the PIIGS (Italy, Portugal and Ireland).

The impulse response (IR) analysis is often combined with Granger-causality. It shows the strength of the response of the variables in the model to a shock introduced to a particular variable. In our case, given that we already know the Granger-causality relations between countries, the IR analysis can be informative in terms of understanding which CDS market has the biggest impact on the CDS markets of the countries in the sample and when the impact lasts the longest.

To address the issue of the ordering of variables we used the generalized impulse response function (GIRF) developed by Pesaran and Shin (1998). It is invariant to changes in the ordering of variables. Another interesting feature of the GIRF is that it is equivalent to an orthogonal impulse response function for the first variable. This permits to estimate the GIRF by calculating the orthogonalized impulse response with each variable as a leading one.

We calculated the generalized impulse response for the crisis period (November 14, 2007 – September 29, 2010) and used six lags as in the Granger-causality test performed for the crisis period. We introduced a positive shock of one standard deviation to the spread of CDS of each country and observed changes in basis points. The positive shock to CDS spreads means an increase of the risk of default on the sovereign debt. The shock in GIRF is not independent for all variables. It hits the whole system according to correlations between CDS spreads of all countries. In general we can observe that the effect of the shock lasts for around 15 days and after that the whole system converges to the initial state. Below we present chosen results.

From Figure 7 we see that the response of the system is relatively strong to a shock in the Spanish and Irish CDS markets (in comparison with a similar shock in the CDS markets of other PIIGS). A shock in Spain causes a turmoil in the CDS spreads of PIIGS, whereas it does not strongly affect core countries. Besides, the shock to the core transmits with some delay.

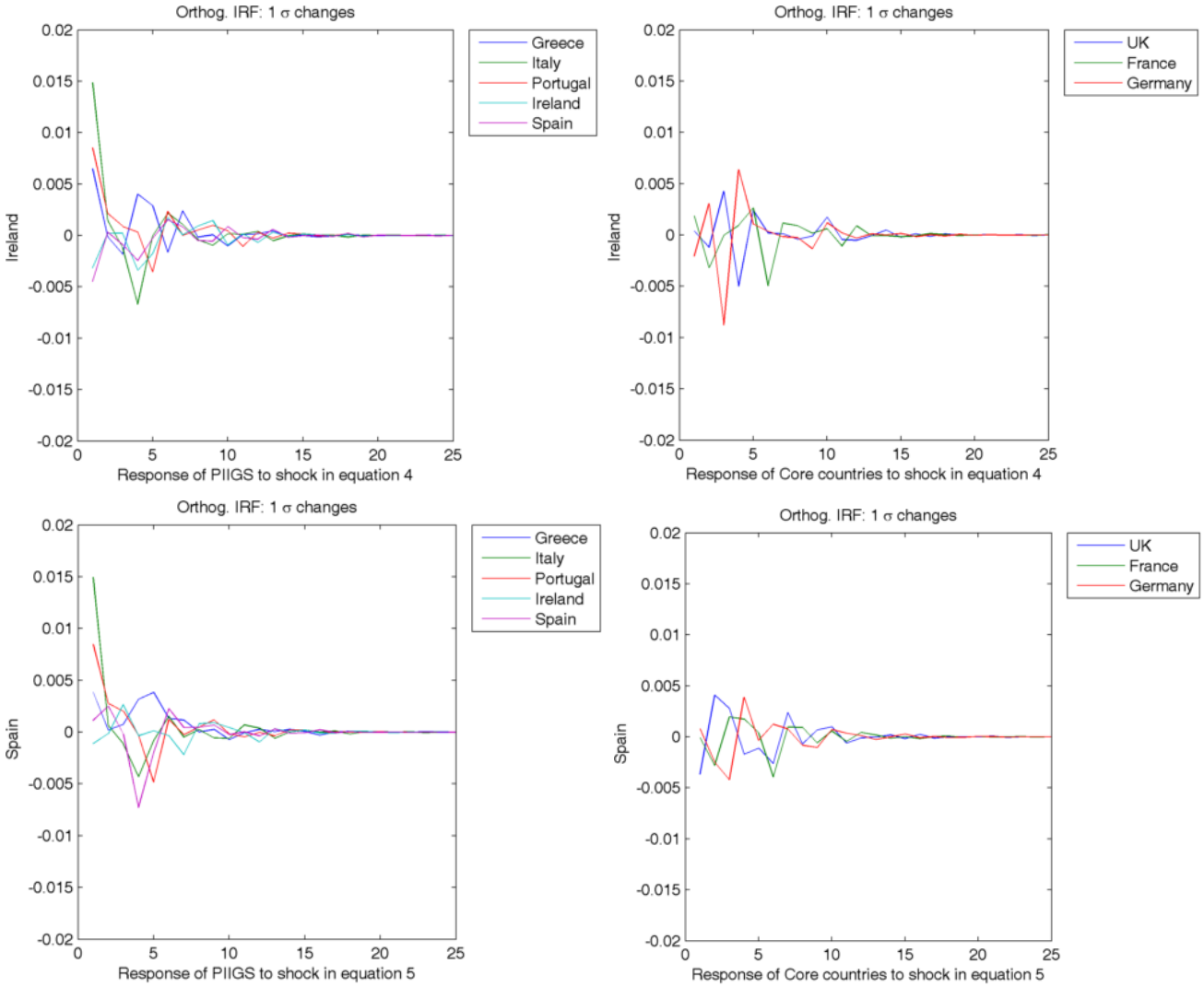

Figure 7. GIRF after one standard deviation shock in the Irish and Spanish CDS

The response of the system to a shock in the French and German CDS markets is also strong, which is understandable if to consider the size of these economies. Interestingly, a shock in the Portuguese CDS market causes a strong response for PIIGS, whereas the response is rather weak for the core, which confirms the results of the Granger-causality test for Portugal.

At the same time, the IR to a shock in the CDS market of Italy and the UK is relatively weak (with the exception of the Italian CDS market that reacts relatively strongly to shocks in the UK). Similarly, the response to a shock in the Greek CDS is weak, especially for Germany, France and the UK (Figure 8).

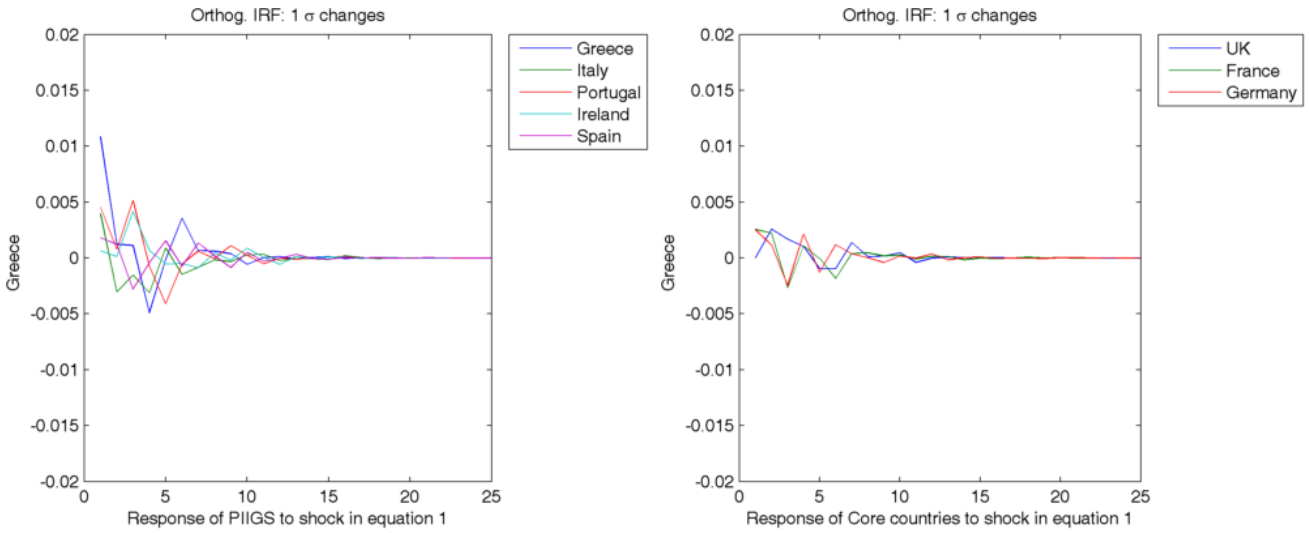

Figure 8. GIRF after one standard deviation shock in the Greek CDS

The Italian CDS market reacts to shocks stronger than the CDS markets of other countries in the sample, whereas the CDS market of the UK has one of the weakest responses. The latter could be explained by the fact that investors perceive the UK as the most immune to the Eurozone problems among the examined European countries.

We performed a robustness test of the results of the impulse response analysis. Unfortunately, the strength and the persistence of responses are not robust to changes in the number of lags in the VAR model, however, the relative differences between CDS markets of the countries in the sample seem to hold.

3.3. Adjusted Correlation Analysis of CDS Spreads Before and After the Greek Bailout

The Granger-causality test and the IR analysis were informative in studying the relationship between CDS markets of the countries in the sample. However, a VAR model requires a sufficient number of observations in order to determine causality. Therefore, for the VAR model we studied a longer crisis period that spanned from the credit crunch in August 2007 through the sovereign debt crisis until September 2010. Since the problems of Greece in March-April 2010 made financial markets extremely nervous it is also important to have a closer look at the relationship between CDS markets just around the period of the Greek bailout in May 2010.

The unconditional Pearson correlation coefficient increases automatically with a surge in volatility during crisis times and, therefore, can provide misleading results[17]. Boyer (1999) and Forbes and Rigobon (2002) suggested the adjustment that considers changes in volatility:

[17] Discussion on this can be found in Kat (2002).

$$\rho^C = \frac{\rho^\rho}{\sqrt{\rho\rho^2 + (1-\rho\rho^2)\frac{\sigma_X^{\#2}}{\sigma_X^{C2}}}} \qquad (5)$$

where $\rho^P = \frac{\mathrm{Cov(X,Y)}}{\sigma_X \sigma_Y}$ is a Pearson coefficient that is calculated for each pair of sovereigns X and Y (we assume that sovereign X is a trigger); $\sigma_X^{\#2}$ and $\sigma_X^{C^2}$ are the variances of CDS spreads of the triggering sovereign before the crisis and during the crisis respectively.

Inspecting equation (5) we see that the conditional correlation coefficient can increase because of the change in the underlying relationship between sovereigns and/or because of the change in volatility. Since we are interested in the increase in the relationship itself we control for volatility by deriving the adjusted correlation coefficient from equation (5).

$$\rho^{Adj} = \frac{\rho^C}{\sqrt{1+(\frac{\sigma_X^{C2}}{\sigma_X^{\#2}}-1)(1-\rho^{C2})}} \qquad (6)$$

ρ^{Adj} can be interpreted as the correlation coefficient adjusted for the bias resulting from an increase in the volatility of CDS spreads during the crisis period. It is coefficient conditional on one of the countries in a correlated pair being in distress (in crisis).

Corsetti et al. (2005) criticized this method of coefficient adjustment. They showed that if the data generating process includes a common factor (ex. interest rates or oil price increase) the adjustment also should depend on the common factor. However, we used the adjustment on the time series between August 2009 and September 2010 and thus eliminated the possible influence of the global financial crisis of 2007-2008 on the Eurozone sovereign debt crisis in our further analysis.

In order to calculate the variance before the crisis $\sigma_X^{\#2}$ we used the time series between August and October 2009 when the volatility and CDS spreads were quite low[18]. The variance during the crisis $\sigma_X^{C^2}$ was calculated for two samples: the period before the first Greek bailout (November 2009 – April 2010) and after (May – September 2010)[19].

Tables 2 and 3 show adjusted correlation coefficients between CDS spreads of the studied countries. These tables are not symmetric because the value of the correlation depends on which sovereign is a trigger. For example, in table 2 the correlation between CDS spreads of Greece and Italy is equal to 0.408 if Greece is a triggering country and 0.617 if it is Italy.

ρ_1 is a **triggering capacity** of each sovereign. It is the sum over rows excluding the sovereign for

[18] Dungey and Zhumabekova (2001) warn against the use of long reference periods as this may bias the results.

[19] On May 2, 2010 Eurozone finance ministers approved a 110-billion-euro loan package for Greece over three years, with 80 billion euros coming from the bloc and the rest from the IMF.

which the value is calculated (i.e., the sum over rows minus one). ρ_n **is a vulnerability of each sovereign** to a joint trigger of all other sovereigns. It is the sum over columns excluding the country for which the value is calculated (i.e., the sum over columns minus one).

Figure 9 displays the triggering capacity ρ_1 of each sovereign against its GDP. GDP serves as a proxy for the relative economic size and strength of each country in the sample. Thus, Germany is the powerhouse of Europe followed by France, the UK and Italy[20]. Besides, both before and after the Greek bailout the triggering capacity of Germany, France and the UK was considerably higher than that of PIIGS. Moreover, correlations of the CDS markets of Germany and France with the CDS markets of other sovereigns grew further after the Greek bailout. A possible explanation for this might be that these countries were the main sponsors of the Greek debt.

Table 2. Adjusted correlations before the first Greek bailout (November 2009 - April 2010)

	Greece	**Italy**	**Portugal**	**Ireland**	**Spain**	**UK**	**France**	**Germany**	ρ_n
Greece	1	0.617	0.543	0.633	0.527	0.576	0.573	0.563	**4.033**
Italy	0.408	1	0.651	0.615	0.72	0.743	0.688	0.66	**4.485**
Portugal	0.429	0.741	1	0.657	0.708	0.655	0.666	0.668	**4.524**
Ireland	0.461	0.656	0.603	1	0.585	0.595	0.546	0.58	**4.026**
Spain	0.413	0.8	0.707	0.639	1	0.698	0.626	0.646	**4.53**
UK	0.295	0.65	0.46	0.455	0.504	1	0.621	0.65	**3.636**
France	0.329	0.637	0.518	0.454	0.478	0.668	1	0.791	**3.876**
Germany	0.29	0.565	0.477	0.445	0.457	0.654	0.755	1	**3.643**
ρ_1	**2.625**	**4.667**	**3.96**	**3.898**	**3.979**	**4.59**	**4.475**	**4.558**	

Table 3. Adjusted correlations after the first Greek bailout (May - September 2010)

	Greece	**Italy**	**Portugal**	**Ireland**	**Spain**	**UK**	**France**	**Germany**	ρ_n
Greece	1	0.427	0.554	0.488	0.451	0.483	0.625	0.58	**3.608**
Italy	0.391	1	0.549	0.648	0.639	0.649	0.705	0.761	**4.342**
Portugal	0.527	0.562	1	0.678	0.604	0.623	0.692	0.696	**4.383**
Ireland	0.435	0.632	0.65	1	0.666	0.634	0.698	0.735	**4.45**
Spain	0.431	0.658	0.609	0.699	1	0.591	0.678	0.75	**4.416**
UK	0.273	0.438	0.403	0.439	0.371	1	0.652	0.7	**3.276**
France	0.34	0.446	0.421	0.454	0.403	0.602	1	0.803	**3.468**
Germany	0.271	0.457	0.38	0.444	0.428	0.601	0.762	1	**3.343**
ρ_1	**2.67**	**3.621**	**3.565**	**3.85**	**3.562**	**4.183**	**4.812**	**5.025**	

Ireland had the highest triggering capacity among PIIGS after the Greek bailout. It may be due to the unprecedented help of its government to the banking sector in September 2010. This pushed the

[20] The ranking of countries may be different depending on which method to measure GDP is used. We use the World Economic Outlook Database of the IMF. We chose the GDP statistics calculated using the current exchange rate method as it offers better indications of a country's relative economic strength.

Irish budget deficit up to around a third of GDP and later led to its EU-IMF bailout in November 2010. The triggering capacity of Italy before the Greek bailout was as high as that of core European countries but it dropped after the bailout to the levels of Spain and Portugal. Surprisingly, both before and after the Greek bailout Greece had the lowest triggering capacity among countries in the sample. This result may possible be explained by the fact that once it became obvious that the Greek crisis is the European Union crisis the CDS market of Greece stopped being the only cause of the problems in the European CDS market. At the same time, the CDS markets of core EU countries became more important since the decisions of investors were mainly based on the probability of a bailout and the willingness of the core to rescue Greece.

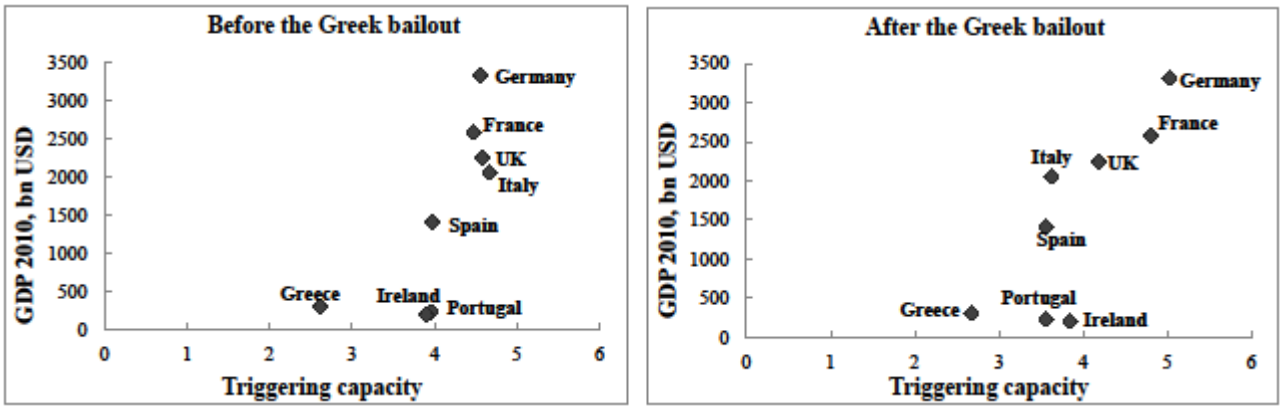

Figure 9. Triggering capacity before and after the Greek bailout

Overall, with the exception of Greece each of PIIGS has a triggering capacity of a similar strength. However, taking into consideration GDP levels we should bear in mind that Italy and Spain are much bigger economies than Greece, Ireland and Portugal and thus may pose a greater threat to the EU in case of default.

Figure 10 displays the vulnerability ρ_n of each country to a joint trigger against each country's banking assets. Assets from the BIS data[21] serve as a proxy for the capacity of each country in the sample to sustain the shock if it is triggered by any other sovereign. Here we see the opposite situation. Overall, in both periods PIIGS are more vulnerable to shocks than core European countries. Besides, the assets of PIIGS are considerably lower than those of the core to be able to absorb the shock from other countries.

What is interesting is that both before and after the Greek bailout Greece was less vulnerable than other PIIGS. Vulnerability of Ireland before the bailout was at the same level as that of Greece but Ireland's assets are considerably higher. Nevertheless, after the Greek bailout Ireland became more vulnerable. The most vulnerable country in the sample is Portugal which is both susceptible to shocks

[21] We used the BIS data from March 2010 for the analysis before the Greek bailout and June 2010 for the analysis after the Greek bailout.

and has low assets to absorb them if it is triggered.

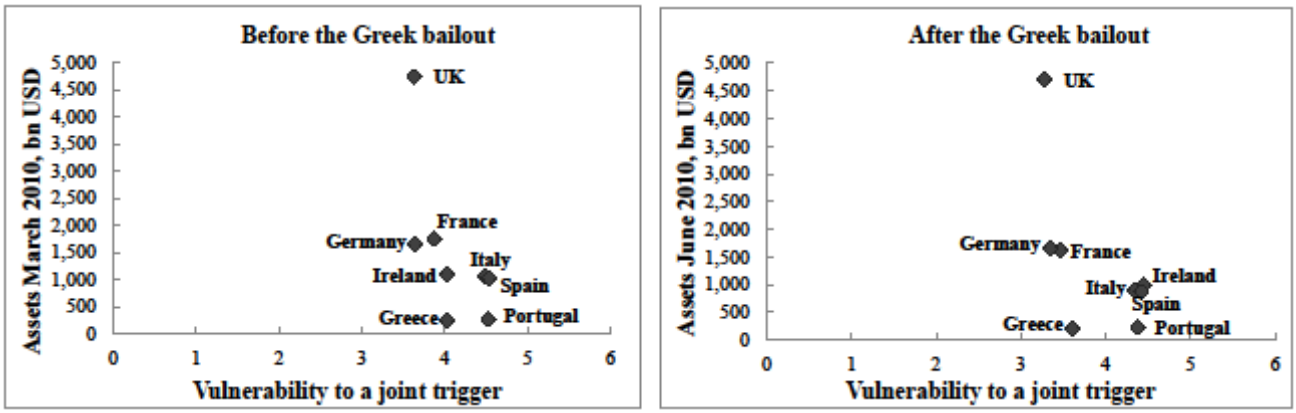

Figure 10. Vulnerability to a joint trigger before and after the Greek bailout

Among core European countries France is the most vulnerable, whereas, the UK has the highest assets (with London being one of the world's largest financial centers) which makes it the least vulnerable to shocks.

Thus, the adjusted correlation analysis confirms that core EU countries (Germany, France and the UK) have both high capacity to trigger other sovereigns and extensive assets to sustain the shock if they are triggered by other countries. On the contrary, Greece and other PIIGS (even Spain and Italy) have lower triggering capacity and considerably lower assets to absorb the shock. Hence they are more fragile to a worsening situation in other countries. The results also suggest that Portugal is the most vulnerable and the UK is the least vulnerable country in the sample.

4. Concluding remarks

This study was designed to examine sovereign risks and the occurrence of financial contagion in PIIGS, France, Germany and the UK. In order to explain the long-term dynamics of the CDS market of these countries we carried out our analysis on the extended time period spanning from August 2005, well before the global financial crisis, until September 2010. The analysis of the data showed that sovereign risk mainly concentrates in the EU countries and that core countries are heavily exposed to PIIGS.

Since contagion is often characterized by increasing correlations we conducted the EWMA correlation analysis. We studied changes in correlations between CDS premia of countries in the sample after the "credit crunch" in August 2007, after the Lehman Brothers collapse, after the sovereign risk in Europe increased in November 2009 and shortly before the EU-IMF Greek bailout in May 2010. We found that there were several waves of contagion. The estimated EWMA correlations increased significantly already after the "credit crunch" and also confirmed the role of the global financial crisis in triggering the sovereign default risk. Similarly, the Granger-causality test

revealed a huge rise in cross-country interdependencies after the global financial crisis as compared with the pre-crisis period. Furthermore, the IRF analysis showed that among PIIGS the CDS market of Spain and Ireland has the biggest impact on the European CDS market, whereas the CDS market of the UK does not cause a big distress in the Eurozone.

In order to have a closer look at the behavior of the CDS market before and after the first bailout of Greece in May 2010 we conducted the adjusted correlation analysis. It confirmed that in both periods Greece and other PIIGS (even Spain and Italy) have lower capacity to trigger contagion than core EU countries (Germany, France, the UK). Besides, Portugal is the most vulnerable country in the sample, whereas the UK is the most immune to shocks.

Both descriptive and model-based evidence point to the fact that the Eurozone CDS market encountered more turbulence during the post-crisis period than before. No doubt, the global financial crisis of 2007-2009 played its role in triggering the sovereign default risk. Nevertheless, financial stability in the Eurozone was also undermined by the specific features of its institutional setup. Being left with no room for manoeuvre in setting their monetary and fiscal policy, Eurozone countries had to compete by adjusting their labour markets. Since historically core EU countries had higher real wages and stronger social policies they managed to shrink their unit labour costs better (with Germany in the lead) than the periphery. As a result, the core accumulated current account surpluses and dominated trade and capital flows in the Eurozone, whereas PIIGS experienced significant erosion of competitiveness leading to substantial current account deficits. These deficits were financed from abroad primarily in the form of lending by core Eurozone banks that laid the grounds for the excessive indebtedness of periphery to the core (Lapavitsas et al. (2010a, 2010b)).

Accordingly, PIIGS had to deal with large fiscal imbalances already before the crisis. However, the weaknesses of the EU monetary and fiscal integration became even more apparent following the onset of the financial crisis as the situation in the triplet of current account deficit, budget deficit and debt to GDP ratio of PIIGS aggravated further. Since credit default swaps are written on government bonds the CDS market quickly reacted to a significant deterioration in the domestic fiscal metrics of PIIGS with wider and more diverse spreads. However, markets reappraised the risks not only for PIIGS, but also for core EU economies as the Eurozone countries are highly integrated economically and financially (via national banking systems). It resulted in stronger causalities between CDS markets in the Eurozone during the post-crisis period.

We have to bear in mind that the empirical results presented in this paper considered changes that happened only in the CDS market. This means that there could be other channels through which contagion could spread. Moreover, our analysis was performed only on the time series until September 2010. Since the situation in the Eurozone is constantly changing it would also be interesting to look at the behavior of the CDS market of studied countries after that period.

Furthermore, the analysis can be easily extended to a larger set of the European Union countries (for instance, new EU members) and thus the findings of this paper leave room for future research.

Though informative, the applied methods are insufficient to clearly answer the question which country would be the next weakest link in case of default of some country. We believe that the use of the network approach may further clarify the issue. In future work we will conduct stress tests on the financial network among sovereigns interconnected according to their debt relationships. It will help us to understand the impact of a possible credit event on the structure of the network and the survival of all the players. Besides, it will allow us to test the results of the present study.

References

1. Acharya, V.V., Drechsler, I., Schnabl, P., 2011. A Pyrrhic victory? Bank bailouts and sovereign credit risk. Working Paper.
2. Aizenman, J., Hutchison, M., Jinjarak, Y., 2011. What is the risk of European sovereign debt defaults? Fiscal space, CDS spreads and market pricing of risk. NBER Working Paper Series, Vol. 17407.
3. Alter, A., Schuler, Y.S., 2011. Credit spread interdependencies of European states and banks during the financial crisis. Working Paper.
4. Boyer, B.H., Gibson, M.S., Loretan, M., 1999. Pitfalls in tests for changes in correlations. International Finance Discussion Papers 597.
5. Caporale, G.M., Cipollini, A., Spagnolo, N., 2005. Testing for contagion: a conditional correlation analysis. Journal of Empirical Finance 12/3, 476-489.
6. Chiang, T.C., Bang, N.J., Huimin, L., 2007. Dynamic correlation analysis of financial contagion: evidence from Asian market. Journal of International Money and Finance 26, 1206-1228.
7. Corsetti, G., Pericoli, M., Sbracia, M., 2005. Some contagion, some interdependence: more pitfalls in tests of financial contagion. Journal of International Money and Finance 24, 1177–1199.
8. Delatte, A.L., Gex, M., Lopez-Villavicencio, A., 2011. Has the CDS market influenced the borrowing cost of European countries during the sovereign crisis? Working Paper.
9. Dieckmann, S., Plank, T., 2011. Default risk of advanced economies: an empirical analysis of credit default swaps during the financial crisis. Review of Finance 15 (4).
10. Dungey, M., Zhumabekova, D., 2001. Testing for contagion using correlations: some words of caution. Pacific Basin Working Paper Series 01-09.

11. Ejsing, J.W., Lemke, W., 2009. The Janus-headed salvation: sovereign and bank credit risk premia during 2008-2009. ECB Working Paper 1127.
12. Ferreira, M.A., Lopez, J.A., 2005. Evaluating interest rate covariance models within a value at risk framework. Journal of Financial Econometrics 3, 126-168.
13. Fontana, A., Scheicher, M., 2010. An analysis of Euro area sovereign CDS and their relation with government bonds. ECB Working Paper 1271.
14. Forbes, K.J., Rigobon, R., 2002. No contagion, only interdependence: measuring stock market comovements. Journal of Finance 57, 2223–2261.
15. Galesi, A., Sgherri, S., 2009. Regional financial spillovers across Europe: a global VAR analysis. IMF Working Paper 23.
16. Gex, M., Coudert, V., 2010. Contagion inside the credit default swaps market: the case of the GM and Ford crisis in 2005. Journal of International Financial Markets, Institutions & Money 20, 109–134.
17. Gray, D., 2009. Financial contagion among members of the EU-8: a cointegration and Granger causality approach. International Journal of Emerging Markets 4 (4), 299-314.
18. Hamilton, J. D., 1994. Time Series Analysis. Princeton University Press.
19. Kat, H.M., 2003. The dangers of using correlation to measure dependence. Journal of Alternative Investments, Vol. 6, No. 2, 54-58.
20. Khalid, A.M., Kawai, M., 2003. Was financial market contagion the source of economic crisis in Asia? Evidence using a multivariate VAR model. Journal of Asian Economics 14, 131–156.
21. Lapavitsas, C., Kaltenbrunner, A., Lindo, D., Michell, J., Painceira, J.P., Pires, E., Powell, J., Stenfors, A., Teles, N., 2010a. Eurozone crisis: beggar thyself and thy neighbour. RMF occasional report, March.
22. Lapavitsas, C., Kaltenbrunner, A., Lambrinidis, G., Lindo, D., Meadway, J., Michell, J., Painceira, J.P., Pires, E., Powell, J., Stenfors, A., Teles, N., 2010b. The Eurozone between austerity and default. RMF occasional report, September.
23. Longstaff, F.A., Pan, J., Pedersen, L.H., Singleton K.J., 2011. How sovereign is sovereign credit risk? American Economic Journal: Macroeconomics 3, 75–103.
24. Lopez, J.A., Walter, C.A., 2000. Evaluating covariance matrix forecasts in a value-at-risk framework. Technical Report 2000-21, Federal Reserve Bank of San Francisco.
25. Morgan, J.P., 1996. RiskMetrics Technical Document, 4th ed. J.P. Morgan, New York.
26. Pan, J., Singleton, K.J., 2008. Default and recovery implicit in the term structure of sovereign CDS spreads. Journal of Finance 63, 2345-2384.

27. Pesaran, H.H, Shin, Y., 1998. Generalized impulse response analysis in linear multivariate model. Economic Letters 58, 17-29.
28. Sander, H., Kleimeier, S., 2003. Contagion and causality: an empirical investigation of four Asian crisis episodes. Journal of International Financial Markets, Institutions & Money 13(2), 171-186.