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ABSTRACT

This work aims to analyze the co-movements between the Portuguese, Greek, Irish and German government bond markets after the subprime crisis (2007 to 2013). Additionally, it aims to test the existence of contagion between the Portuguese, Greece and Irish bond markets, and to explore the phenomenon of flight-to-quality from the Portuguese and Greek bond markets to the German market. The analysis is undertaken using a DCC-IGARCH model with daily data for the 10 year yields government bonds. Results suggest the existence of contagion between the Greek and the Portuguese markets, and to a lesser extent between the Irish and the Portuguese markets. The correlation between the Portuguese and Greek yields at the end of the analyzed period indicates the non-existence of decoupling between the two countries. During most of the identified crisis periods, flight-to-quality flows are evident from the Portuguese and Greek bond markets to the German market.

KEYWORDS

financial contagion; flight-to-quality; European Sovereign Debt Crisis; DCC-GARCH model.

JEL CODES: E43, E44 e G15

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1. INTRODUCTION

Greece has been blamed for triggering a contagion effect that started the Eurozone crisis. In this context, this paper aims to investigate the relationship between the bond markets of those countries most affected by the European Sovereign Debt Crisis, which also requested external financial assistance (Portugal, Greece and Ireland), from January 2007 to March 2013.

It is important to understand whether for these peripheral countries public debt costs grew due to increased credit risk or due to the existence of contagion, since this has implications on the adequate policy measures to undertake. The existence of contagion calls for an European institutional response to support countries in financial stress by providing liquidity and avoid the spread of problems to other countries. The study of contagion is also relevant for financial investors, because it reduces the advantages of international risk diversification, with implications for risk management.

We complement the works of Missio and Watzka (2011) and Arghyrou and Kontonikas (2012) which conclude that contagion from Greece to various countries of the euro area, including Portugal, took place.

This paper has three main goals. Firstly, it aims to determine if there was evidence of contagion between Portugal, Greece and Ireland. Secondly, the study aims to ascertain the existence of flight-to-quality capital flows from the Portuguese and Greek bond markets to the German bond market during crisis periods. Thirdly, being Ireland, a country considered among market participants better off than Greece and Portugal, it will also be possible to test if the Portuguese bond market is approaching the Irish, as some market news suggested (Economic Daily 2012, 2013) or if on the contrary, it remains highly correlated with the Greek bond market.

We use daily data for 10 year maturity yields of government bonds. The methodology is based on a model DCC-IGARCH (Dynamic Conditional Correlation - Integrated Generalized Autoregressive Conditional heteroskedasticity) to obtain dynamic correlations between pairs of yields.

This paper presents the following contributions to the literature. Firstly, it combines the methodology DCC-IGARCH with the identification of several crises periods, attempting to assess the existence of contagion in those periods. The focus is on particularly strong and short periods of market stress, unlike other papers that define a large crisis period, which usually starts in 2009 with the disclosure of the huge Greek budget deficit. In addition, this article focuses on the issue of flight-to-quality in the context of the European sovereign debt crisis.

Results reveal that there was contagion between the Greek and the Portuguese bond markets in most of the crisis periods identified. To a lesser extent, significant contagion between Portugal and Ireland was also observed. The sovereign bond market of Portugal does not seem to be decoupling from

Greece or coupling with Ireland. In what concerns flight-to-quality, there is evidence of such a phenomenon from both Portugal and Greece to Germany in most of the identified crisis periods.

This paper is organized as follows. In Section 2, the theoretical framework and review of the literature on contagion and the public debt crisis in the euro area is presented. In Section 3, we expose the hypotheses to be studied, describe the data used and the methodology. In Section 4, we introduce the results of the empirical analysis. Finally, we present our conclusions in Section 5.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

In this section, we present a review on the literature about the public debt crisis in the Eurozone and its origins, as well as studies about financial contagion during the sovereign debt crises.

Sovereign Debt Crisis origin in the Eurozone

There are several possible reasons for the European Sovereign debt crisis, some more related with the way the European Monetary Union (EMU) is designed, others related to country-specific situations. Regarding issues related to the monetary union, according to De Grauwe (2011) a national bond market in a monetary union is very vulnerable because domestic policy makers do not control money issuing, and therefore they are not able to ensure debt holders that they are going to have the necessary liquidity to pay them. Contagion between different bond markets could only be stopped if a central bank were available to assume the position of lender of last resort. This position was not immediately assumed by the ECB.

According to Arghyrou and Tsoukalas (2011) and Arghyrou and Kontonikas (2012) contagion can be understood in the context of second generation exchange rate crises models. The authors state that by the end of 2008 and the beginning of 2009, agents believed that the deterioration of Greek macroeconomic fundamentals became inconsistent with its permanence within the monetary union. The country went from a situation where investors believed in its permanence in the euro area, with an implicit guarantee of Treasury bonds by the other countries of the union, to a situation where the permanence in the union was not credible and where the implicit guarantee of bonds disappeared (Arghyrou and Kontonikas, 2012). This lead investors to demand very large interest rates and the decision to stay in the euro area became much more costly. However, speculation did not play a major role in the increase of interest rates.

Moreover, with multiple equilibria deriving from the existence of problems in market coordination, fundamentals cannot alone explain how a country moves from one equilibrium to another (Pericoli and Sbracia, 2003). However, fundamentals can explain why certain countries are more vulnerable to crisis than others.

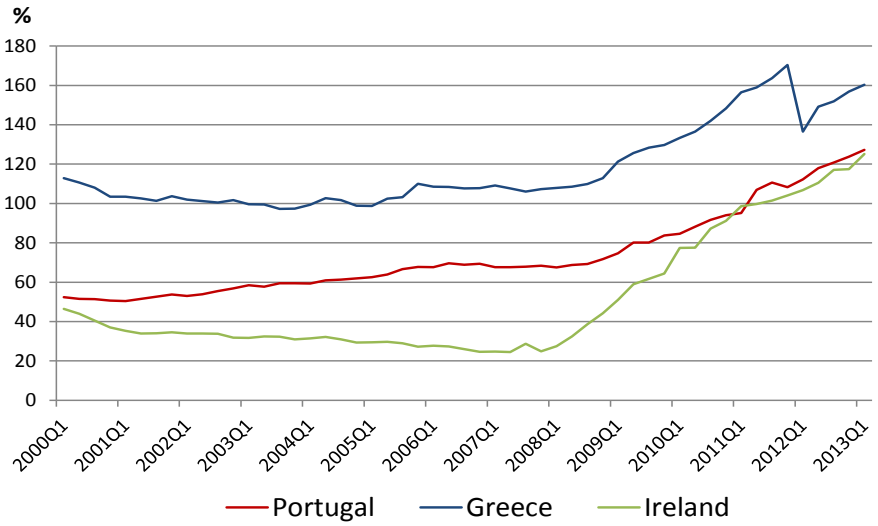
The sovereign debt crisis in the euro area highlighted some weaknesses of the EMU, namely the large structural differences among member-states, the peripheral economies' macroeconomic disequilibria and the strong correlation between country's risk and banking risk. According to Reinhart and Rogoff (2010), sovereign debt crises usually tend to be preceded by crises in the banking system.

Higgins and Klitgaard (2011) also refer to this weakness of the economies that lost their monetary policy autonomy. They claim that the low interest rates available to all countries joining the EMU, specifically to the peripheral economies (where interest rates used to be much higher), led to an increase in external debt (both of public and private sectors). Before joining the EMU, peripheral countries had a weak currency that helped to sustain exports and growth. After the euro they lost the option to adjust their own exchange rate, and the challenge was now to control domestic expenditure in order to maintain a sustainable growth.

Higgins and Klitgaard (2011) deepen the specificity of each peripheral country. In both Portugal and Greece indebtedness occurred to finance the deterioration of domestic savings, while in Spain and Ireland it financed investment in real estate causing a bubble in this sector. Furthermore, in Ireland, there were problems related to toxic subprime products, whereas in Portugal, Spain and Greece the growth potential did not increase in order to pay for the debt. In Portugal both private and public sectors suffered from excess indebtedness, whereas in Greece the problem was more focused on the high level of public debt.

According to Eurostat (Figure 1), even before joining the EMU, Greece already had high levels of public debt. After joining the euro, low interest rates and easy access to credit allowed the country to continue increasing public indebtedness. On the other hand, Portugal used to have levels of public debt lower than 60% (until Q1 2004) and Ireland had a public debt situation even better than Portugal.

Figure 1 - Public debt as a percentage of GDP, quarterly data. Source: Eurostat, 2013



Banking system problems caused by the subprime played a central role in the triggering of the euro sovereign debt crisis. During the latter months of 2008, government and central banks' actions to support the financial system intensified, trying to mitigate the effects on the real economy. In addition, the crisis reduced tax revenues and increased public expenditure (through fiscal stabilizers and accommodative fiscal policy), translating ultimately into an increase in public deficits and debt. By the end of 2009, Greece announced its public deficit to be largely higher than previously estimated, raising the concern about its public debt sustainability and pressing public debt yields higher. This situation ended in the external joint-intervention of the IMF (International Monetary Fund), ECB (European Central Bank) and the European Commission. Quickly the effects of the crisis in Greece spread to other countries in the euro area, which were victims of an unprecedented crisis of confidence, with speculative attacks on sovereign securities and with successive downgrading of their debt, inducing Ireland, Portugal and later Cyprus, to ask for international financial aid.

As shown by Balli (2009), risk perception associated with public bonds of countries joining the Eurozone changed dramatically with the sovereign debt crisis. The author proves that after the creation of the euro, fiscal and other macroeconomic variables no longer explained yield fluctuation. The general belief was that if one country could not honor its commitments, the payment would be ensured by the whole EMU, so yields were all close to each other. After the eruption of the sovereign debt crisis, the confidence in the monetary union evaporated, with investors reflecting the levels of debt and economic indicators of each country on yields (Afonso, Arghyrou and Kontonikas, 2012).

Thus, Portugal, Greece and Ireland had high interest rate spreads relative to the German public bonds during the euro area sovereign debt crisis (Figure 2). These spreads are essentially linked to the credit risk premium, which depends on the level of public debt and on fiscal policies

(Hsing, 2010, for Estonia); and on the risk related with recessions and macroeconomic factors (Ludvigson and Ng, 2009).

Spreads started to decrease for Ireland from mid-2011, for Portugal from the beginning of 2012, and for Greece from mid-2012. The fall of spreads in 2012 is linked to the statement of ECB that it would do everything necessary to support the euro (July 2012) and the announcement of the readiness to do Outright Monetary Transactions (OMTs) in secondary markets of euro area sovereign bonds (summer 2012) – see ECB, 2010; ECB, 2011; ECB, 2012; ECB, 2013; and ECB, 2014 for a description of the monetary policy and bond market situation in 2010-14. In 2009 the ECB had already initiated a programme to buy covered bonds in euros (Covered Bonds Purchase Programme - CBPP). This was extended in 2011 (CBPP II), with the main goal of restabilising monetary policy transmission in the face of the malfunctioning of markets. Another non-conventional policy was the Security Market Programme started in May 2010 directed to buy public and private debt securities.

Another factor contributing to the decline of spreads was the decision of the ECB in December 2011 to follow non-standard monetary policy measures to ensure liquidity to banks: conduct longer-term refinancing operations (LTROs) with a maturity of three years and the increase in collateral accepted to lend money to banks. In the first quarter of 2012 these operations were initiated with positive effects on the markets. In the same period, there was a private sector swap of Greek debt that improved the sustainability of the public debt.

Overall, the fall in spreads of the peripheral countries continued in 2013 due to better perspectives of economic growth that promoted the search for higher yields, and the re-enforcing of the expansionary nature of the ECB policy, both in terms of LTROs and reduction of key interest rates (two reductions were operated during this year) - (Banco de Portugal, 2013). In July 2013, the ECB declared in its forward guidance that it would maintain interest rates at low levels for a long period. The successful end of the financial help to Ireland and Spain also contributed to the reduction of spreads in 2013. Portugal and Ireland improved their conditions to a point that would allow future access to primary bond markets.

However, from January to May 2013 uncertainties emerged in the euro area bond market with flight-to-quality movements, one of the reasons being the financial assistance program to Cyprus.

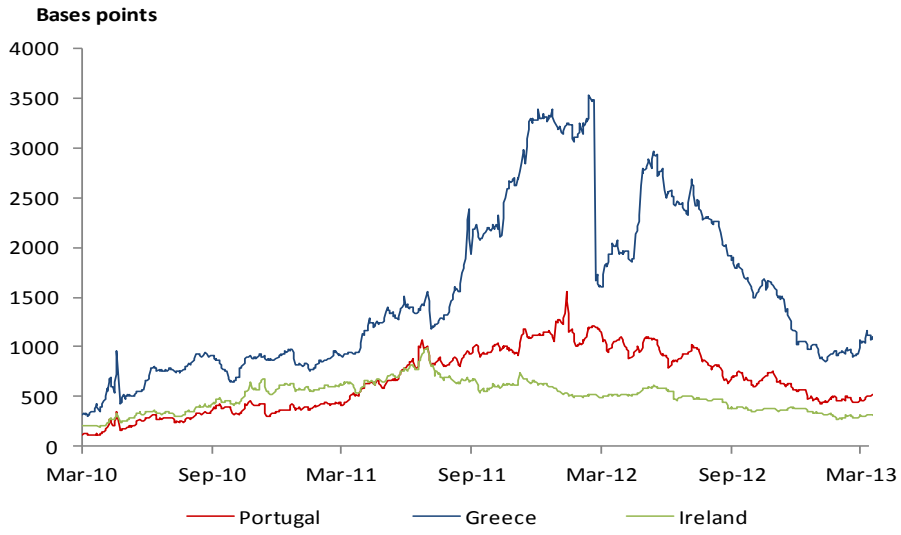
In 2014, the successful exit of Portugal from the financial support program contributed to the continuation of the decline of its yields and of the ones of peripheral countries, which allowed Portugal to regain access to the bond market. The euro area countries which had better macroeconomic and fiscal fundamentals were the ones that registered the largest decline in yields (ECB, 2014). From June to October 2014, the ECB continued with the decrease in key interest rates and with LTROs, started the purchase of selected private sector assets (Asset-Backed Security –

ABSPP) and continued the covered bond programme (CBPP III). At the beginning of 2015 the ECB decided to also buy securities issued by governments following a policy of quantitative easing, with a considerable impact on reducing the yields.

The ABS programme aims to increase liquidity of banks, liberate capital, and allow banks to take full advantage of the LTROs (Altomonte and Busolli, 2014). The announced programme of buying unlimited public debt from countries in difficulty in the secondary markets had a significant positive effects on the yields of Italy and Spain, with spillovers to the credit market and economic growth (Altavilla et al., 2014).

Since our goal is to study situations of crisis that could give rise to flight to quality and contagion, we stop our analysis in early 2013 because yields spread start to decline strongly.

Figure 2 - Difference between 10-years government bond yields of Portugal, Greece2 and Ireland compared to Germany, in base points (bp), from March 2010 to March 2013, daily data. Source: Bloomberg, 2013.



[2] The sharp drop in yields on government bonds of Greece, in March 2012, was due to the restructuring of Greek debt that consisted of a swap of debt with private creditors (implementation of the PSI-*Private Sector Involvement*). The operation involved the forgiveness of € 100 billion by these investors, reducing the weight of the debt.

Financial contagion

Financial contagion has been studied especially in emerging countries' crises. Currently, due to the recent subprime and euro sovereign debt crises and their fast spread to several countries that initially had no problems, the contagion of crises became a subject of special interest.

Despite the vast literature on the subject, there is no consensus on the definition of financial contagion and about the methodology that should be used to test it. Nevertheless, it is generally accepted that contagion implies that the links between markets intensify after the occurrence of a shock in one market, and thus the collapse of one of them leads to the fall of the others (Forbes and Rigobon, 2002). This concept cannot be confused with interdependence, which does not imply a change in the relationship between markets (Gonzalo and Olmo, 2005).[3]

The definition of contagion adopted in this work is that contagion is a significant increase in co-movements of asset prices across markets, relative to a standard period, conditional on a crisis occurring in one market or group of markets (Pericoli and Sbracia, 2003). Consequently, the methodology used in this work is based on the calculation of the correlation coefficient, which is usually applied by the authors that follow this definition.

However, in the literature on financial contagion, the authors are divided into two sides (Masson, 1999; Pritsker, 2001; Forbes and Rigobon, 2002): those who support the fact that contagion exists due to changes in macroeconomic fundamentals in each country and those who argue that contagion happens through the action of international investors. On one hand, the former group of authors indicate that changes in macroeconomic fundamentals of a country makes it more vulnerable in a crisis. The existence of strong trade links between countries in the euro zone and the effect of the sovereign debt crisis on the banking system constitute potential channels of contagion (Sachs, Tornell and Velasco, 1996).

On the other hand, the authors that point to international investors as being responsible for contagion refer to the existence of behaviors that increase systemic risk, such as "herd behavior", panic or changes in the investor's sentiment (Forbes and Rigobon, 2002). The role of *predatory trading* was studied by Brunnermeier and Pedersen (2005)*; wealth constraints* was analyzed by Kyle and Xiong (2001), and *portfolio rebalancing* was studied by Boyer et al. (2006). In particular, p*ortfolio rebalancing* is the attempt by investors to adjust their portfolios to changes in the risk of each country after the occurrence of shocks removing funds from countries that did not suffer a direct shock but that are perceived as affected. The contagion by portfolio rebalancing may occur either through *flight-to-quality* from stocks to bonds or through *cross-market rebalancing* (involving different national markets).

[3] In this case there is no contagion because the correlation between markets does not increase.

Contagion has been studied in several financial markets, including the bonds market. Caceres and Unsal (2013) analyze the yields and volatility of treasury bonds in the Asian market after the collapse of the Lehman Brothers. The authors conclude that contagion did take place and that the overall risk aversion factor had different effects depending on the country: countries such as Australia benefitted with the increase in the overall risk (the yields decreased) benefiting from the increase in *safe-haven* flows; while countries such as the Philippines, India and Malaysia were penalized and their sovereign bonds yields increased. Finally, the fundamentals of each country had an impact on spreads, with spreads increasing, namely when fiscal balances deteriorated.

During the European sovereign debt crisis, Arezki et al. (2011) find that *flight-to-quality* can explain the variation of CDS spread in response to ratings' changes. Dajcman (2012) finds that after the start of the sovereign debt crisis in the euro zone, *flight-to-quality* from stocks to sovereign bonds ceased to exist in most of the affected countries.

Regarding contagion in Eurozone bond markets, Missio and Watzka (2011) use a DCC-GARCH model to analyze the existence of contagion in a group of 6 euro area countries (Portugal, Spain, Italy, Belgium, Holland and Austria) during the period of December 31, 2008 to December 31, 2010. They conclude that there was contagion from Greece to Portugal, Spain, Italy and Belgium, in the summer of 2010. However, the authors emphasize the idea that contagion worsened country fundamental problems that already existed.

Likewise, Afonso, Arghyrou and Kontonikas (2012), Arghyrou and Kontonikas (2012) and Constâncio (2012) show that there was contagion from the Greek sovereign debt crisis to most countries of the Monetary Union, mainly to Portugal, Ireland and Spain, countries with weaker macroeconomic fundamentals. In opposition, Pragidis et al. (2015) concludes that there was no contagion from Greece to other countries, but instead a decoupling between countries notably between Greece and the other PIIGS.

In conclusion, the existence of contagion from Greece to other peripheral countries is confirmed by empirical works and it is justified by the characteristics of the Eurozone: existence of countries with weak fundamentals, strong commercial connections, change in expectations about the stay of countries in the EMU, the fact that the central bank did not act as lender of last resort, and strong dependence between bank risk and sovereign risk. The contagion effect was stronger for the GIP group (Greece, Ireland and Portugal), with Ireland showing less structural problems, and Greece with the worst situation in terms of public debt and with the largest difficulty in implementing recessionary fiscal measures. The *flight-to-quality* effect, i.e. increase in flows to assets considered a *safe-haven*, should also be noted, because it was identified in Asian economies between 2005 and 2010.

3. DATA, METHODOLOGY AND HYPOTHESES.

In this section the hypotheses are introduced, the data are described and the methodology is presented.

Data and econometric methodology

In this work, as is usual in the literature, we use yields[4] of treasury bonds with 10 years of maturity taken from Bloomberg. The data frequency is daily and covers the period from 1 of January 2007 to 28 of March 2013, except for Ireland's series that cover the period from 1 November 2007 to 28 of March 2013 due the unavailability of previous data. The change in yields was computed as:

$$\text{Change in yields}_t = ln(\frac{Y_t}{Y_{t-1}}) \quad (2)$$

where Y_t is *yield* in *t*.

The contagion of the crisis is usually associated with increased co-movements in the returns of financial assets (measured by increased correlation). In this work, we use a bivariate-GARCH model (for each pair of countries) in order to model the conditional variance and correlation of the series over time. Namely, we use the Dynamic Conditional Correlation – GARCH model (DCC-GARCH) (Engle, 2002) that allows us to compute dynamic correlations correcting for heteroskedasticity. This model is parsimonious and the correlation matrices estimated are positive definite, the results are easy to interpret and the correlation between assets changes over time as required in the study of contagion.

The DCC-GARCH model describes the conditional variance and correlation of various series and consists of a non-linear combination of univariate GARCH-models. According to Naoui, Liouane and Brahim (2010) and Missio and Watzka (2011), creating the model goes through two steps: first, we estimate the conditional variance of each variable using a univariate ARCH process; second, we use the standardized residuals from the completion of the first step to model the conditional correlation. Each asset follows a GARCH process:

$$h_{i,t}=\omega_i + \alpha_i e^2_{i,t-1} + \beta_i h_{i,t-1} \quad (4)$$

Hereby h_t represents the conditional variance, e_t the filtered residual with zero mean and ω, α's and β's the parameters to be estimated.

[4] Generic yield: value of the sovereign bond yield that is the benchmark.

The residuals are filtered using an ARIMA model in order to eliminate autocorrelation and to get zero average. Through the estimation of univariate GARCH models - equation (4), it is possible to obtain a matrix of standardized residuals ε_t needed to create the DCC-GARCH model.

In a DCC(1,1) model, the dynamic covariance is estimated according to the following equation[5]:

$$Q_t=(1- \alpha - \beta) \quad \hat{O} \quad + \alpha\varepsilon_{t-1} \varepsilon'_{t-1} + \beta Q_{t-1} \qquad (6)$$

Q_t is the time-varying covariance matrix of the standardized residuals ε_t resulting from the univariate GARCH equation; $\hat{O}$ is the unconditional covariance matrix of the standardized residuals; the α's and the β's are parameters to be estimated by the DCC model, being non-negative scalars and $\alpha + \beta < 1$. More precisely, the α's represent the reaction of the covariance to past shocks and the β's represent the reaction of the covariance to the previous covariance.

The unconditional covariance matrix $\hat{O}$ is positive definite and past shocks ($\varepsilon_{t-1} \varepsilon'_{t-1}$) are positive semidefinite, therefore also Q_t will be positive definite, because it is an weighted average of a positive definite matrix and a positive semidefinite matrix.

The normalization of equation (6) is then done to arrive at the dynamic correlation matrices R_t:

$$R_t = Q^*_t{}^{-1} Q_t Q^*_t{}^{-1} \qquad (7)$$

Where Q^*_t is a diagonal matrix with the square roots of the diagonal of Q_t as diagonal elements. The elements of R_t will be $\rho_{ijt} = q_{ijt} / \sqrt{(q_{ii}q_{jj})}$, ρ_{ijt} is the correlation coefficient between two assets, with the diagonal of R_t containing the correlation coefficients of an asset with itself, that is 1. R_t allows us to derive the dynamic conditional correlation to test our hypotheses.

The covariance matrix of filtered residuals (and not standardized) that vary over time is derived according to equation (8):

$$H_t= D_tR_tD_t \qquad (8)$$

[5] The DCC model can be generalized in order to have more lags of Q or more lags of the cross product of errors.

Where H_t is the covariance matrix; D_t is the diagonal matrix of standard deviations time variant, i.e. $D_t = \text{diag}(h_{11t}^{1/2},..., h_{nnt}^{1/2})$ and each h_{iit} is the conditional variance described as a univariate GARCH model (equation (4)). [6]

As an illustration of the model, take the DCC – GARCH (1,1) for Portugal and Greece:

$$r_{GR,t} = \gamma_{GR} + e_{GR,t}$$

$$r_{PT,t} = \gamma_{PT} + e_{PT,t}$$

$$h_{GR,t} = \omega_{GR} + \alpha_{GR} * e^2_{GR,\,t-1} + \beta_{GR} * h_{GR,t-1}$$

$$h_{PT,t} = \omega_{PT} + \alpha_{PT} * e^2_{PT,\,t-1} + \beta_{PT} * h_{PT,t-1}$$

$$Q_{DCC,t} = (1- \alpha_{DCC} - \beta_{DCC}) * \hat{O} + \alpha_{DCC} * \varepsilon_{t-1}\, \varepsilon'_{t-1} + \beta_{DCC} * Q_{t-1}$$

Contagion and flight-to-quality test

In order to test contagion and flight-to-quality we look at changes in the correlation between bond markets as in Baur and Lucey (2009), which study the co-movement between the bond market and the stock market in the same country. According to these authors, there is evidence of contagion when the correlation coefficient between both markets has a significant increase in a crisis period, relative to a benchmark period of normality, and with a positive coefficient. Flight-to-quality occurs when there is a significant decrease in the correlation coefficient in a crisis period, and it assumes negative values. When the study is conducted on the relationship between the stock and the bond market, flight-to-quality means a movement of flows from stocks to bonds. In our case, since we are studying only the bond market there is flight-to-quality from the market where losses are more pronounced (the market in crisis) to the market where losses are smaller or non- existent (Table 1).

[6] GARCH-Multivariate model was estimated using RATSS 8.0 program.

Table 1 –
Interpretation of correlation coefficient between bond market A and bond market B.

Situation	Larger decline in market A	Larger decline in market B
Coefficient is positive, varies positively and stays positive	Contagion	
Coefficient is positive, varies negatively and stays positive.	Nothing takes place	
Coefficient is positive, varies negatively and becomes negative.	Flight to market B	Flight to market A
Coefficient is negative, varies positively and stays negative.	Nothing takes place	
Coefficient is negative varies negatively and stays negative.	Flight to market B	Flight to market A
Coefficient is negative, varies positively and becomes positive.	Contagion	

This methodology demands the definition of the crises periods. The crises periods are identified according to the behavior of the Portuguese, Greek and Irish bond markets. A crisis period is identified when there are at least two days in three weeks or less where the daily changes in yields are larger than 1.65 times the returns' standard deviation of the total sample (which corresponds to less than 5% probability of occurrence in a normal distribution). When there is a case with the same characteristics in less than ten days it means that the crisis is prolonged. The rule "at least two days in three weeks" was the one that best identified the crisis periods according to the prior knowledge that we have of the major crises periods. In order to calculate the change in the correlation in the crisis period we need a benchmark period, which is defined as thirty days prior to the crisis.

The existence of contagion between the Portuguese and the Greek bond markets, and the Portuguese and Irish bond markets are the first and the second hypotheses to test, respectively. The existence of flows of *flight-to-quality* from the Portuguese and Greek bond markets to the German bond market are the third and fourth hypotheses to test.

4. EMPIRICAL ANALYSIS

Preliminary Analysis and definition of the crisis periods to be studied

First, we confirmed that the series of returns are stationary using the ADF test (See Table A1).[7] Next, using the methodology described above, we estimated for each series (of the first differences of yields) the most appropriate ARIMA model using the Schwarz criterion. The autocorrelation in each series was eliminated (Table A2 in the appendix) with an ARMA model (12,4) for Portugal [8], an ARMA (6,8) [9] for Greece, an AR (1) model for Ireland and an AR (3) for Germany. The residuals of these models are the ones used in the multivariate GARCH and denominated filtered residuals.

Using the methodology described in the previous chapter, we identified 12 crisis periods for the Portuguese bond market and 10 periods for the Greek bond market, from January 2007 to March 2013. A total of 18 crises periods in both markets were studied. For the cases in which there is a crisis in both countries, the longer crisis was considered. In what concerns the relationship between the Portuguese and Irish markets, only two crises periods originated in the Irish market.

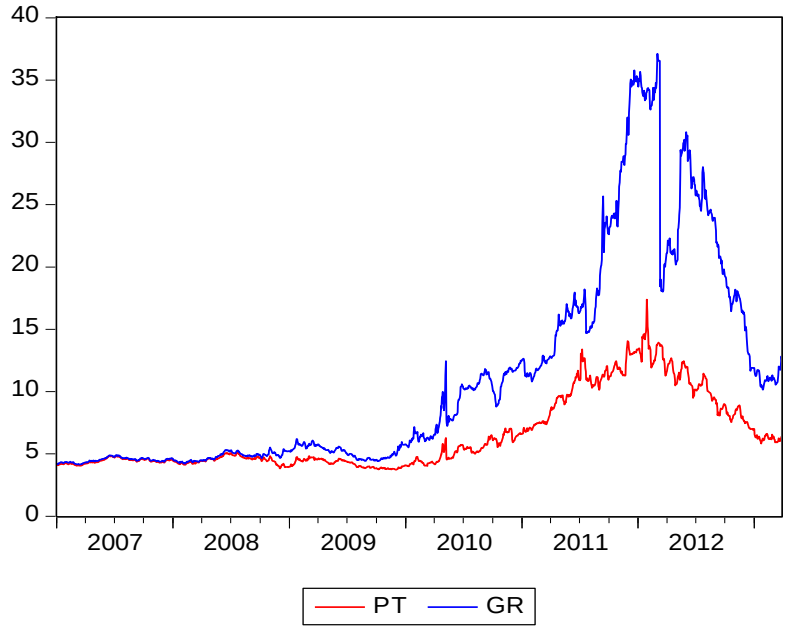
In what follows, firstly we assess the hypothesis making a graphic and qualitative analysis on the evolution of the correlations throughout the analyzed periods. We study the tendency of the correlation over long periods, looking for relevant evidence to test the hypotheses, namely to analyse the decoupling between Greece and Portugal. Secondly we carried out a more detailed analysis for the identified crisis periods to test for the existence of contagion or flight-to-quality.

Portugal and Greece

The objective here is to find out whether there was contagion between the Portuguese and Greek markets. In order to obtain the correlation, we used the model DCC - IGARCH. An integrated model was used due to the fact that the sum of conditional variances coefficients of the GARCH model were higher than 1. We performed tests for the absence of ARCH effects, no autocorrelation and normality of residuals (Table A3). Only the normality assumption was rejected, and thus a multivariate student distribution was used with the estimated degrees of freedom. [10]

[7] These results were confirmed using the Phillips-Perron and the KPSS tests.
[8] The autoregressive terms from -2 to -5 and from -7 to -11 and the *moving-average* terms from -1 to -3 were not significant and were removed.
[9] The autoregressive terms -1, -4 and -5 and the *moving-average* terms from -2 to -7 were not significant and were removed.
[10] In all the below models we use IGARCH and the student distribution for the same reason.

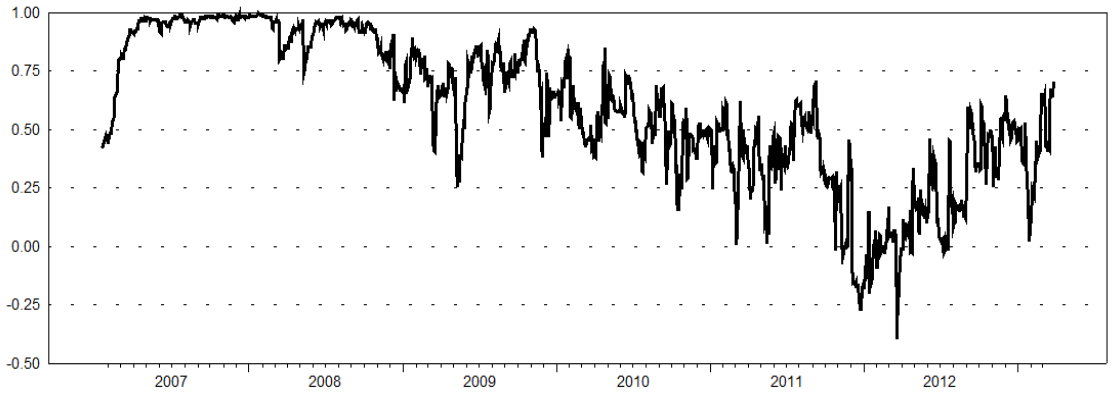
Figure 3 - 10-years Portuguese and Greek government bond yields, as a percentage. Source: Bloomberg, 2013.



Until the Subprime Crisis (Q4 2008) the 10-year Portuguese and Greek government bonds yields were very similar (Figure 3) and the correlation between both series was close to 1 (Figure 4). From the Subprime Crisis onwards there is a downward tendency in the correlation, that however stays positive, and the yields also became more distant from each other. It is important to highlight the significant increase in the correlation after the Financial Assistance Program enforcement in Portugal (April 2011). This increase occurred together with the increase in yields in both markets, which brings the evidence of contagion with risk premium increasing for both countries.

From August 2011 to the end of that year, there was a decrease in the correlation, reaching -0.25, indicating a decoupling of the Greek and Portuguese situations. Later in 2012, the correlation grew again after having been negative at the beginning of the year. Yields also increase for both countries, but with a greater increase for the Greek bonds. In the beginning of 2013, the correlation fell sharply. This fall was interrupted by the crisis in Cyprus. Therefore, evidence does not confirm the news of an existing decoupling in both bond markets up to March 2013.

Figure 4 - Correlation between 10-year Portuguese and Greek bonds (IGARCH-DCC(1,1) Model).



Turning now to the hypothesis of contagion during the crisis periods, we performed a more detailed analysis of the correlation between the two markets, studying the 18 identified periods in both bond markets (Table 2). There was contagion in 11 of those periods (61% of the crisis episodes). In all main crises episodes – subprime, crisis in Greece, Portugal and Cyprus – we found evidence of contagion.

Table 2 - Identified Crises in the Portuguese and Greece markets.

Cause	Period	Number of crisis days	Number of days with market stress	Yields change in crisis period	Correlation before the crisis period	Correlation during the crisis period	Results
Subprime I	04-12-2008 to 08-12-2008	3	2	0.0661 (PT[11])	0.8418	0.8512	Contagion
Subprime II	06-01-2009 to 22-01-2009	13	3	0.1670 (PT)	0.7463	0.7206	Nothing takes place
Downgrade of Greek rating (Note 1)	09-12-2009 to 15-12-2009	5	2	0.0680 (GR[12])	0.7493	0.6343	Nothing takes place
Maintenance of the negative outlook for Portuguese rating (Note 2)	27-01-2010 to 03-02-2010	6	3	0.1008 (PT) 0.1417 (GR)	0.6607	0.7911	Contagion
Sovereign debt crisis in Greece	06-04-2010 to 14-05-2010	29	8	0.8086 (GR)	0.4700	0.6040	Contagion
Markets instability (Greek crisis) (Note 3)	15-06-2010 to 23-06-2010	7	2	0.2359 (GR)	0.6072	0.6997	Contagion
Markets instability related to Ireland (Note 4)	16-09-2010 to 20-09-2010	3	2	0.1060 (PT)	0.5691	0.4973	Nothing takes place
Sovereign debt crisis in Ireland	27-10-2010 to 10-11-2010	11	4	0.2432 (PT)	0.4105	0.4511	Contagion
Downgrade of Greek rating to non-investment grade (Note 5)	06-01-2011 to 18-01-2011	9	2	0.0607 (PT)	0.4747	0.3669	Nothing takes place
Markets instability related to Portugal (Note 6)	18-04-2011 to 27-04-2011	8	2	0.1667 (GR)	0.3487	0.4879	Contagion
Sovereign debt crisis in Portugal	06-07-2011 to 11-07-2011	4	2	0.1978 (PT)	0.3744	0.3836	Contagion

[11] PT: Crisis identified in the Portuguese sovereign bond market.
[12] GR: Crisis identified in the Greek sovereign bond market.

Table 3 - Identified Crises in the Portuguese and Greece markets (continuation)

Cause	Period	Number of crisis days	Number of days with market stress	Yields change in crisis period	Correlation before the crisis period	Correlation during the crisis period	Results
Downgrade of Italian rating (Note 7)	05-09-2011 to 20-09-2011	12	2	0.1333 (PT)	0.5535	0.5698	Contagion
Markets instability related to Greece (Note 8)	26-10-2011 to 01-11-2011	5	2	0.0243 (GR)	0.3194	0.2027	Nothing takes place
Political instability in Spain and Italy	24-11-2011 to 30-11-2011	5	4	0.2350 (PT)	0.1617	0.2919	Contagion
Rating downgrade of several countries (Note 9)	16-01-2012 to 30-01-2012	11	2	0.3696 (PT)	-0.1370	-0.0659	Nothing takes place
Granting of second international aid package to Greece.	22-03-2012 to 23-03-2012	2	2	0.1071 (GR)	0.0199	-0.2983	Flight to Portuguese market
Instability related to Greece and Spain (Note 10)	04-05-2012 to 18-05-2012	11	2	0.1357 (PT)	0.0397	0.1559	Contagion
Sovereign debt crisis in Cyprus	19-03-2013 to 27-03-2013	7	2	0.1344 (GR)	0.4303	0.6136	Contagion

Note:

- No. of days with stress: no. of days in which the yields variance exceeded the standard deviation of the series times 1.65.
- Yields variation in the crises period: proportional change in yields accumulated during the period. (using a geometric average);
- Correlation between the crisis periods: the average correlation 30 days before the start of the period.
- Correlation during the crisis period: average correlation during the crisis period.

Note on the cause of crisis periods:

1- Rating agencies Fitch and Standard & Poor´s (S&P) downgraded Greek sovereign debt; 2 - Fitch declares it would keep the negative outlook for Portuguese sovereign debt, also stating that a downgrading would be more likely to happen. The Portuguese Treasury and Public Debt Agency (IGCP) had difficulties in issuing debt; 3- Market instability associated to Greek sovereign debt crisis; 4- Ireland´s central bank announced that the cost of the bailout of Anglo Irish Bank (nationalized by the Irish government in January 2009) could reach €34.3 bn. This situation would push the budget deficit to 32% of GDP. Investors also had concerns regarding Portugal's public accounts; 5 – Rating agency Fitch downgrades the rating of Greek sovereign debt to non-investment grade, with negative

outlook, making it equivalent to the rating assigned by the agencies S&P and Moody´s; 6- Market instability related to the request for economic and financial assistance programme by Portugal; 7 – Rating downgrade of Italian sovereign debt by S&P with negative outlook; 8 – Instability related to the program of financial assistance to Greece; 9 – Rating downgrades by the agency S&P of the sovereign debt of 9 euro area countries, including Portugal, that became non-investment grade by the three major rating agencies; 10 – Political instability in Greece; bailout request by the fourth largest Spanish bank (Bankia).

Portugal and Ireland

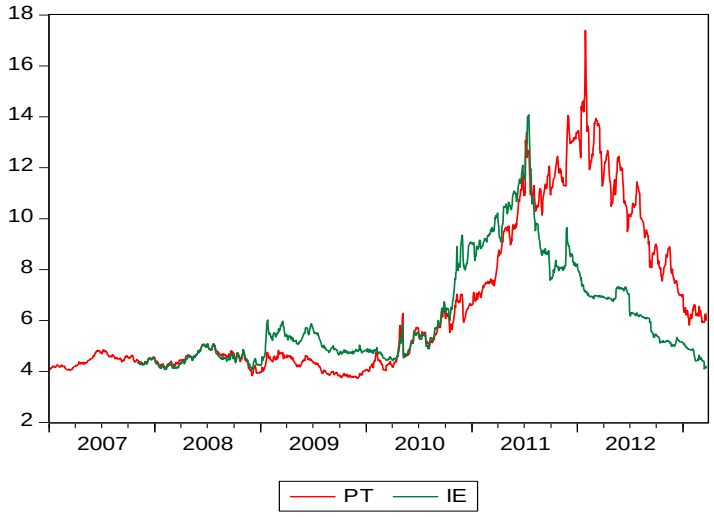
In order to see if the existence of contagion is a phenomenon specific to Portugal and Greece, the countries which were most affected by the crisis, we also studied the relationship between the sovereign bond markets of Portugal and Ireland.

Starting with the graphical and qualitative analysis of the correlation between both markets and observing yields series in

Figure **5**, it is possible to see that yields are relatively close until the Irish demand for external intervention (November 2010), Portuguese yields being slightly lower. After this, Irish yields grew rapidly, with the Portuguese ones meeting them in April 2011. After that date, the Irish yields began to decline, while Portuguese yields kept growing.

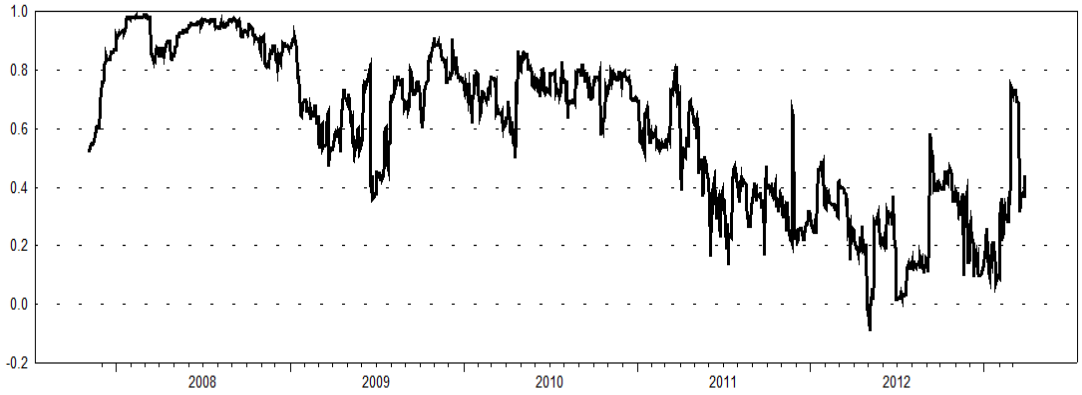
According to the correlation between both markets obtained with the DCC-IGARCH (1,1) model (Bloomberg, 2013. Figure 6), it can be observed that the correlation is always positive (except in May 2012). One can also say that the correlation has a downward tendency until the end of 2011, when a new but undefined tendency starts. It is important to mention that, after the Irish intervention, in November 2010, there is a strong drop in the Portuguese and Irish yields' correlation.

Figure 5- Portuguese and Irish 10-year Government Bonds Yields, in percent. Source:



Bloomberg, 2013.

Figure 6 - Correlation Portugal-Ireland (IGARCH-DCC(1,1) Model).



In 2013, correlation grew in parallel with a decline in the yields of both countries. During this period, there was a perception, among investors, that Portugal was following Ireland on the way to recovery, stepping away from Greece. In March 2013, the correlation fell again despite staying positive, most likely due to difficulties in the negotiation of the Cyprus rescue plan. It is important to remember that during this period, there was an increase in the correlation between Portugal and Greece (see above), which might indicate that Portugal was getting closer to Greece rather than to Ireland.

In a more detailed analysis, studying the identified crisis periods in the Portuguese and Irish markets, contagion was found in 6 of the 12 crisis periods, that is, 50% of the periods (Table 4). During the main episodes of crisis (Subprime, Greece, Ireland and Portugal crises), only in the Greek Crisis was there contagion. This confirms the results present in the literature about the existence of contagion between Greece, Portugal and Ireland, but the market perceives the distance between the Irish and Portuguese case as being larger than between the Greek and Portuguese one.

Table 4 - Identified Crises in the Portuguese and Irish markets. (Notes on crisis periods: **see Table 2)**

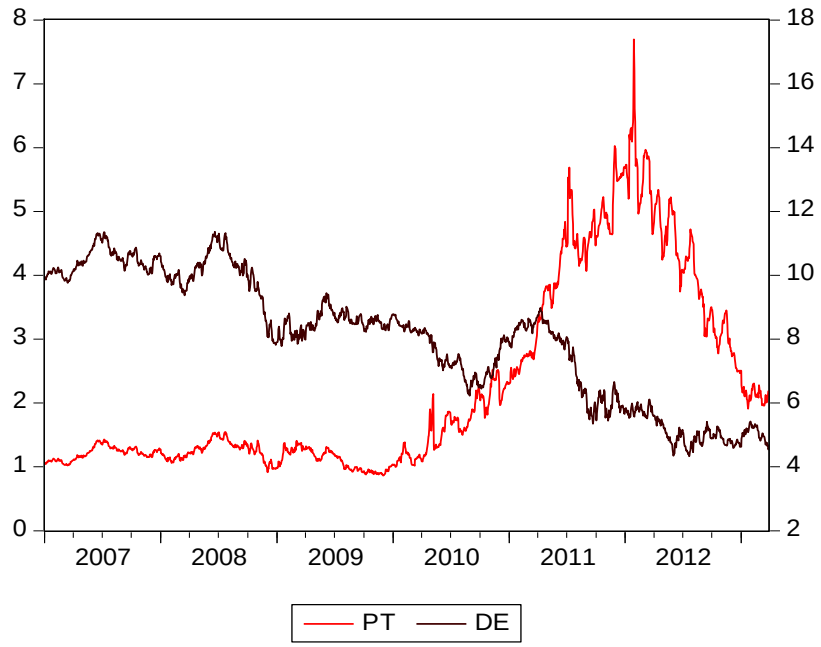
Cause	Period	Number of crisis days	Number of days with market stress	Yields change in crisis period	Correlation before the crisis period	Correlation during the crisis period	Results
Subprime I	04-12-2008 to 08-12-2008	3	2	0.0661 (PT[13])	0.8687	0.8271	Nothing takes place
Subprime II	06-01-2009 to 22-01-2009	13	3	0.1671 (PT)	0.8650	0.8512	Nothing takes place
Maintenance of the negative outlook for Portuguese rating (Note2)	28-01-2010 to 03-02-2010	5	2	0.1008 (PT)	0.7430	0.7674	Contagion
Sovereign debt crisis in Greece	22-04-2010 to 06-05-2010	11	6	0.2677 (PT)	0.6271	0.7843	Contagion
Market instability related to Ireland (Note4)	25-08-2010 to 23-09-2010	22	5	0.2012 (IR[14])	0.7248	0.7773	Contagion
Sovereign debt crisis in Ireland	19-10-2010 to 24-11-2010	27	11	0.4543 (IR)	0.7562	0.7256	Nothing takes place
Greek debt was downgraded to a non-investment rating (Note5)	06-01-2011 to 18-01-2011	9	2	0.0607 (PT)	0.7436	0.5717	Nothing takes place
Sovereign debt crisis in Portugal	06-07-2011 to 11-07-2011	4	2	0.1977 (PT)	0.3583	0.2495	Nothing takes place
Italian debt was downgraded (Note7)	05-09-2011 to 20-09-2011	12	2	0.1333 (PT)	0.3797	0.3815	Contagion
Political instability in Spain and Italy	24-11-2011 to 30-11-2011	5	4	0.2350 (PT)	0.3224	0.4078	Contagion
Rating downgrading of several countries (Note9)	16-01-2012 to 30-01-2012	11	2	0.3696 (PT)	0.2621	0.4368	Contagion
Instability related to Greece and Spain (Note10)	04-05-2012 to 18-05-2012	11	2	0.1357 (PT)	0.1865	0.0786	Nothing takes place

[13] PT: Crisis identified on Portuguese sovereign bond market.
[14] IR: Crisis identified on Irish sovereign bond market.

Portugal and Germany

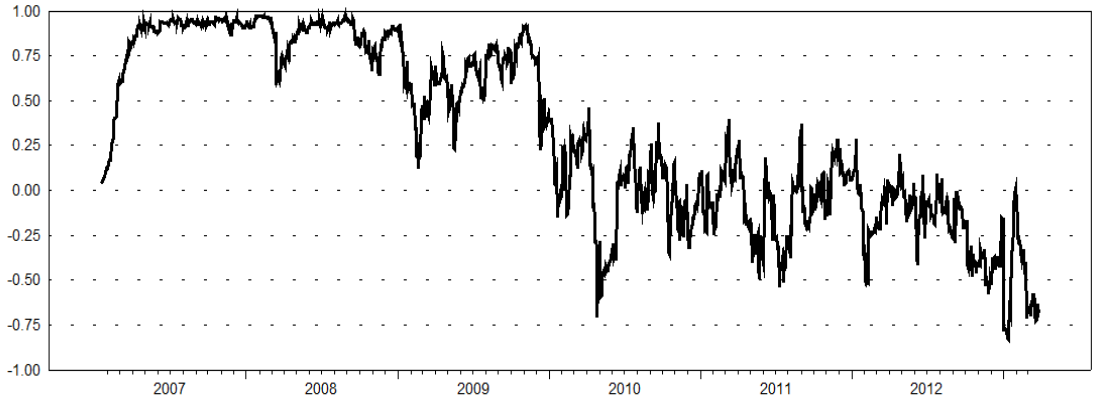
Now we turn to the relationship between the German and Portuguese government bond markets. The aim is to test whether there was evidence of fight-to-quality from Portugal to Germany. According to the result we got from the DCC-IGARCH model, the correlation between 10-year German and Portuguese government bonds yields (Figure 8) is close to 1 from 2007 to Q2 2008, declining strongly thereafter due to the Subprime crisis. The same picture is obtained by analysing the levels of the yields, which were very similar in both countries until September 2008 (Figure 7). By the end of 2009, the correlation between the two markets was close to zero, becoming negative with the Greek sovereign debt crisis in early 2010, which ended up creating the need for external intervention on April 23rd 2010. It is at the end of 2009 that the yields of both countries started to diverge, with the Portuguese yields reaching more than 16%, while the German ones decreasing to values close to 1%. Between November 2009 and April 2010, the correlation dramatically declined from 0.8 to -0.7. From that period on, the correlation oscillated between positive and negative values, being negative most of the time. Observing Figure 7, where we have the Portuguese and German yields, from 2010 to 2012, one can verify that the yields were moving in opposite directions to each other during most of this time, with German yields declining while the Portuguese ones were growing. This translates into the higher demand for low risk bonds due to the increase in risk aversion during the Euro sovereign debt crisis.

Figure 7- Portuguese (right side scale) and German 10-year government bonds yields, in percent. Source: Bloomberg, 2013.



Taking into account when external intervention formally started in Portugal (April, 6th 2011) and when its rating was considered at non-investment grade by the three main rating agencies (January 2012) – two paradigmatic periods of the Portuguese sovereign debt crisis – we reach the conclusion, observing Figure 8, that there was a decrease in the correlation, going from positive to negative. This suggests the occurrence of the flight-to-quality phenomenon in both periods.

Figure 8 - Correlation Portugal - Germany (IGARCH-DCC(1,1) Model).



A deeper analysis of the crisis periods shows (Table 5) evidence of flight-to-quality from the Portuguese to the German market in 8 of the 12 identified crisis periods for the Portuguese market (2/3 of the periods). It is important to point out that in one of the periods where there is no evidence of flight-to-quality, it is directly related to the sovereign debt crisis of the whole Eurozone. Moreover, the existence of contagion occurs only in crisis episodes not directly related to Portugal. This indicates that the crisis in Portugal did not impose a systemic risk for the Eurozone and Germany.

Table 5 - Identified crisis for the Portuguese government bond market.

Cause	Period	Number of crisis days	Number of days with market stress	Yields change in crisis period	Correlation before the crisis period	Correlation during the crisis period	Results
Subprime I	04-12-2008 to 08-12-2008	3	2	0.0661	0.7666	0.8678	Contagion
Subprime II	06-01-2009 to 22-01-2009	13	3	0.1671	0.8795	0.7508	Nothing takes place
Maintenance of negative outlook for Portuguese rating (Note2)	28-01-2010 to 03-02-2010	5	2	0.1009	0.2585	-0.0303	Flight to German market
Sovereign debt crisis in Greece	22-04-2010 to 06-05-2010	11	6	0.2678	0.2188	-0.4108	Flight to German market
Market instability related to Ireland (Note4)	16-09-2010 to 20-09-2010	3	2	0.1060	0.0169	0.1552	Contagion
Sovereign debt crisis in Ireland	27-10-2010 to 10-11-2010	11	4	0.2432	0.0571	-0.0124	Flight to German market
Greek debt was downgraded to a non-investment rating (Note5)	06-01-2011 to 18-01-2011	9	2	0.0607	-0.1067	-0.1382	Flight to German market
Sovereign debt crisis in Portugal	06-07-2011 to 11-07-2011	4	2	0.1978	-0.1523	-0.3122	Flight to German market
Italian debt was downgraded (Note7)	05-09-2011 to 20-09-2011	12	2	0.1334	-0.0922	-0.1366	Flight to German market
Political instability in Spain and Italy	24-11-2011 to 30-11-2011	5	4	0.2350	0.0300	0.2498	Contagion
Rating downgrading of several countries (Note9)	16-01-2012 to 30-01-2012	11	2	0.3696	0.1005	-0.0247	Flight to German market
Instability related to Greece and Spain (Note10)	04-05-2012 to 18-05-2012	11	2	0.1357	0.0106	-0.0830	Flight to German market

Notes on crisis periods: see Table 2.

Greece and Germany

Now, a similar analysis is undertaken of the Greek and German markets during the crisis periods identified for the Greek market. Observing the yields (Figure 9), we can see that it is the subprime crisis at the end of 2008 that causes markets to diverge. Correlations (Figure 10) computed through the econometric DCC – IGARCH (1,1) model show that the values are close to 1 from 2007 to Q2 2008. We also observe evidence of flight-to-quality at the end of 2009, with correlation shifting from positive to negative values, such as in the Portugal-Germany case, assuming values even more negative in early 2010, when the IMF-EU program for Greece was initiated. It is interesting to notice that this large fall in correlation between Portugal and Germany and Greece and Germany occurred at the end of 2009. In November and December 2009, incorrect practices were identified in Greece revealing the true value of the Government Debt, which caused an immediate downgrading of Greek bonds into non-investment grade. It is also important to note that from this date onwards, the correlations between the Portuguese and German bond markets and the Greek and German bond markets were negative for most of the time. However, the Greek rescue plan led to a short-run increase in the correlation with Germany. The same benign effect is observed for Portugal (with an increase in the correlation with Germany and mostly a decrease in the correlation with Greece) and for Ireland (with a decrease in the correlation with Portugal).

Figure 9- German (right side scale) and Greek 10-year government bonds yields, in percent. Source: Bloomberg, 2013.

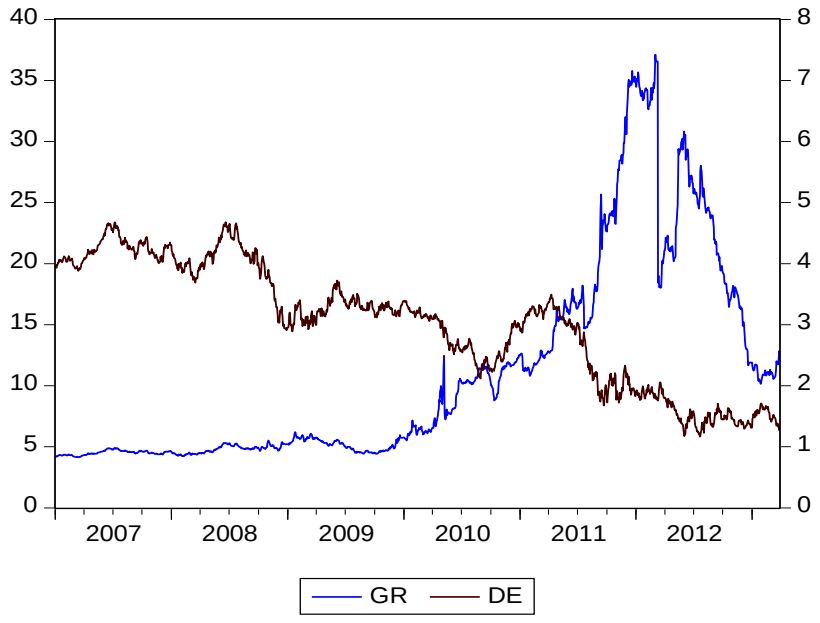
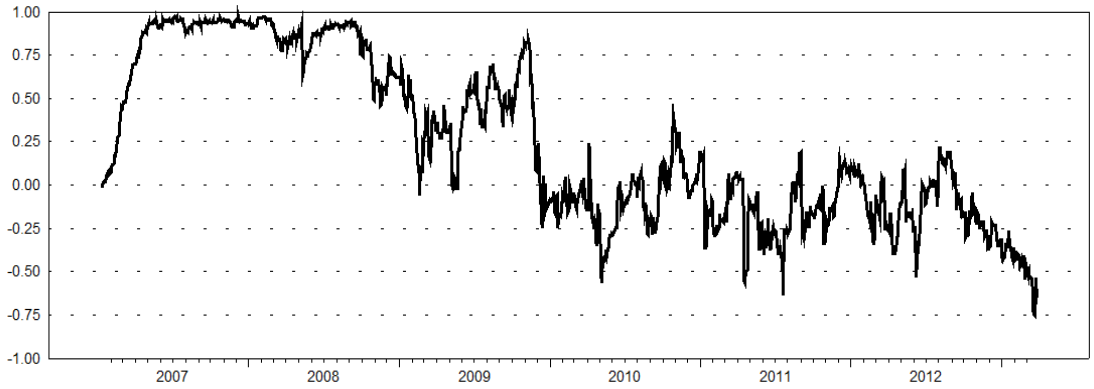


Figure 10 - Correlação Grécia-Alemanha (Modelo IGARCH-DCC(1,1)).



It is important to note that during the sharp drop of the correlation in 2013 (and since September 2012), the yields increased in the Greek market and decreased in the German market, which is indicative of an increasing risk aversion. This behavior is also verified, but with less intensity, in the Portuguese market. In any case, the decrease in the correlation between the two peripheral countries and Germany could be an indicator that the European market for government bonds was far from reaching stability in March 2013.

A deeper analysis of the correlation between the Greek and German markets allows us to point out evidence of flight-to-quality in 7 of the 10 identified periods of crisis (in 70% of the periods) (Table 6).

Table 6- Identified Crisis for the Greek Bond market.

Cause	Period	Number of crisis days	Number of days with market stress	Yields change in crisis period	Correlation before the crisis period	Correlation during the crisis period	Results
Downgrading of Greek rating (Note 1)	09-12-2009 to 15-12-2009	5	2	0.0680	0.5112	-0.2285	Flight to German market
Maintenance of negative outlook for Portuguese rating (Note2)	27-01-2010 to 28-01-2010	2	2	0.1418	-0.1242	-0.1982	Flight to German market
Sovereign debt crisis in Greece	06-04-2010 to 14-05-2010	29	8	0.8087	-0.0657	-0.2523	Flight to German market
Market instability related to Greece (Note3)	15-06-2010 to 23-06-2010	7	2	0.2359	-0.3508	0.0327	Contagion
Market instability related to Portugal (Note6)	18-04-2011 to 27-04-2011	8	2	0.1667	0.0291	-0.5383	Flight to German market
Downgrading of Italian rating (Note7)	05-09-2011 to 19-09-2011	11	4	0.2270	-0.0677	-0.2364	Flight to German market
Market instability related to Greece (Note8)	26-10-2011 to 01-11-2011	5	2	0.0243	-0.1540	-0.2185	Flight to German market
The second program of external help to Greece.	22-03-2012 to 23-03-2012	2	2	0.1071	-0.1719	-0.0854	Nothing takes place
Instability related to Greece and Spain (Note10)	07-05-2012 to 15-05-2012	7	3	0.4095	-0.2660	0.0309	Contagion
Sovereign debt crisis in Cyprus	19-03-2013 to 27-03-2013	7	2	0.1344	-0.4929	-0.7137	Flight to German market

Notes on crisis periods: see Table 2.

5. CONCLUSION

This paper contributes to the literature on contagion during the European sovereign debt crisis, focusing on Portugal and Greece. Its main innovative points are the study on contagion during periods of particular market stress, and the assessment of flight-to quality to the German market. Our results show, that in most of the crisis periods there is contagion between peripheral countries (Portugal-Ireland and mostly Portugal-Greece). In contrast, in the majority of the crises identified there was evidence of flight-to-quality from the Portuguese and Greek bond markets to the German one.

On the contrary to financial news, we do not confirm decoupling between the Portuguese bond market and the Greek bond market until early 2013. In what concerns the relationship between the Portuguese and Irish bond markets, from May 2012 there was an upward trend in the correlation, albeit with significant fluctuations, this increase in correlation being weaker than the increase in the correlation between Greece and Portugal. This is a sign that a significant coupling between Portugal and Ireland did not exist.

We also observe that the major structural break in the correlation between Portugal and Germany, and Greece and Germany was between the end of 2009 and May 2010, *i.e.* between the discovery of the true values of the Greek debt and the approval of the Greek rescue plan. This shows the importance of the Greek episode at the beginning of the euro sovereign debt crisis.

In terms of economic policy, the existence of contagion in the majority of the crisis periods identified highlights the importance of governments and central banks to act promptly to avoid the worsening of the situation. According to Missio and Watzka (2011), with evidence of contagion, the requests for external assistance conducted in several euro area countries were a reasonable decision by governments. Constâncio (2012) also mentions the great importance of the role of central banks to contain the financial contagion. Afonso, Arghyrou and Kontonikas (2012) and Constâncio (2012) point out that the solution to the crisis has to be on the substantial improvement of the countries fundamentals, in articulation with other measures to contain contagion.

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7. APPENDIX

Table A1 – Output of unit root test (ADF test) of the 10-year bond yields series of Portugal, Greece, Ireland and Germany

	P-Value, Series in levels	Result	P-Value, Series in 1st differences	Result
Portugal	0.6333	Non stationary	0.0000	stationary
Greece	0.5579	Non stationary	0.0000	stationary
Ireland	0.5622	Non stationary	0.0000	stationary
Germany	0.8829	Non stationary	0.0000	stationary

Table A2 – Output of autocorrelation tests of the 10-years bond yields series, using Eviews.

Series	Q(10) stat.	P-value
Portugal	14.975	0.092
Greece	4.3555	0.824
Ireland	5.9759	0.817
Gernany	14.825	0.139

Table A3 – Test on no ARCH effects, no autocorrelation, and normality of residuals.

Countries	**ARCH Test (multivariate)** **p-value of estat. χ^2**	**Autocorrelation Test (univariate)** **p-value of estat. Ljung Box lag (40)**	**Normality Test (univariate)** **p-value of Jarque Bera statistics**
Portugal and Greece	0.9974	PT: 0.2234 GR: 0.2352	PT: 0 GR: 0
Portugal and Ireland	0.9944	PT: 0.4189 IE: 0.2647	PT: 0 IR: 0
Portugal and Germany	0.1582	PT: 0.3425 DE: 0.4182	PT: 0 AL: 0
Greece and Germany	0.4816	GR: 0.2289 DE: 0.4223	GR: 0 AL: 0