"Contagion effects in the European NYSE Euronext stock markets in the context of the 2010 sovereign debt crisis"

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Abstract

This paper analyzes the contagion effects of the Greek stock market to the European stock markets of Belgium, France, the Netherlands and Portugal, in the context of the 2010 sovereign debt crisis. The authors perform two tests of contagion using copula models. The first test assesses the existence of contagion on the relevant markets and the second compares contagion intensity during the 2008 subprime crisis and the 2010 European sovereign debt crisis. Results of the first test suggest that contagion exists only in the Portuguese stock market. The other three markets in the sample show interdependence but no contagion. The second test shows that the contagion effects of the 2008 subprime crisis are clearly more intense than those caused by the 2010 sovereign debt crisis. These results provide useful information to market participants. In particular, securities regulators can better understand stock markets crises to take adequate measures to mitigate or prevent contagion episodes.

Keywords: financial contagion, 2010 European sovereign debt crisis, 2008 subprime crisis, stock markets, copula theory.
JEL Classification: F30, G14, G15.

Introduction

The study of financial contagion has caught significant attention from the specialized financial literature. Several reasons could justify the need to identify the presence of contagion in the markets. We highlight two reasons.

First, financial crises are recurring phenomena that modern economies are facing and can have serious consequences on the real economy, particularly in terms of loss of economic growth and employment, and increased risk for institutions that operate globally. Therefore, the knowledge of the existence of contagion episodes is important so that the relevant authorities can take objective measures to mitigate or prevent the contagion related to financial crises, including paying special attention to the regulation of financial institutions that operate internationally.

Second, the specific phenomenon of contagion in capital markets may have implications in the management of portfolios of financial assets, including the decisions of international diversification of risk. If the correlation between the returns of financial assets in international markets increases after a negative shock in a market in a given country, this could undermine the benefits of diversification at a time when such benefits are most needed (Longin and Solnik, 2001; Angand Chen, 2002; Ang and Bakaert, 2002).

The 2008 financial crisis that emerged following the bursting of the US subprime bubble, has been, from an early stage, analyzed from a perspective of contagion. Before the subprime crisis has reached its peak in September 2008, when the bankruptcy of Lehman Brothers took place, Horta et al. (2010) measured the effects of contagion in stock markets of Belgium, France, the Netherlands and Portugal, and concluded for a generalized presence of contagion in these markets. The authors used the definition of contagion proposed by Forbes and Rigobon (2002) and used the copula methodology to measure the dependence structures between the market where the crisis began (US) and the European markets in the sample. They divided the sample into two periods: a tranquil period, between January 2005 and July 2007, and a crisis period, between August 2007 and April 2008, and found out that the correlations drawn from the estimated copulas increased significantly from the tranquil to the crisis period.

Horta et al. (2012), using an extended dataset (with a crisis period ranging from August 1, 2007 to December 7, 2009) studied the transmission channels of the subprime crisis in the same markets. They corroborated the results of Horta et al. (2010), concluding for the existence of financial contagion.

In this study we extend the two previous analyses by broadening the scope of the analysis to the 2010 sovereign debt crisis, which began in Greece.

The public disclosure of sovereign debt problems in Greece began in late 2009 when a new government took office and revealed that the country had been overspending. It was also made public that the country had hidden the true size of the deficit, which reached 12.7% of GDP, more than four times the limit allowed by the EU. In response to pressures from the EU and the financial markets, Greece announced an ambitious plan to control the public accounts, which aimed to restore its deficit below 3% of GDP by 2012 (Standard and Poor's, 2010).

However, despite the intention of the new government, doubts regarding the success of Greece to fulfill the plan arose. The rating agencies have issued negative opinions about the Greek accounts, further increasing the distrust of markets. On December 8, 2009, Fitch lowered Greece's long term debt rating from 'A-' to 'BBB+'. This was the first time in 10 years that the rating of Greece was classified by this agency below the grade 'A-'. This negative context contributed to the increase in Greek debt yields traded in the secondary market and made the funding of the Greek state in the primary market more difficult. These events led to the beginning of the 2010 sovereign debt crisis.

In this study we contribute to the literature on financial contagion by analyzing the effects of contagion that the sovereign debt crisis of 2010 brought to the European stock markets of Belgium, France, the Netherlands and Portugal (stock markets of NYSE Euronext group). Studies of contagion in stock markets in the context of this debt crisis are still scarce and, to the best of our knowledge, the analysis of these specific markets has not yet been done.

We perform two statistical tests, inspired by the methodology of Horta et al. (2010). In the first test, we investigate whether the indices representing the stock markets in the sample exhibit signs of contagion. We consider as the focus of the crisis the index representing the Greek stock market. In the second test, making use of some results of Horta et al. (2012), we check whether the contagion effects of the 2008 subprime crisis are more intense than those of the 2010 sovereign debt crisis. To the best of our knowledge, the comparison of the intensities of these two crises is also a novelty in the literature. The results show that contagion only exists in the Portuguese stock market and the 2008 financial crisis was clearly more intense than the 2010 sovereign debt crisis.

The rest of the paper is organized as follows. In section 1 we identify some recent studies on financial contagion in the context of the 2010 sovereign debt crisis. In section 2 we describe the data and the methodology. In section 3 we discuss the results and the final section draws the main conclusions.

1. Financial contagion in the context of the 2010 sovereign debt crisis

In this section we refer to the work of Kodres and Pritsker (2002) to classify the studies into three categories of contagion, in the context of the 2010 of sovereign debt crisis.

According to Kodres and Pritsker (2002) there are three branches in the literature on financial contagion. The first relates the currency crises to the weaknesses of monetary and financial sectors, including financial market imperfections and weaknesses of the economic policies of governments. The second branch focuses on systemic linkages between financial institutions, considering these institutions as the main cause of crisis transmission. The third focuses on contagion between financial markets, in particular between debt and stock markets.

In the first branch we include the study of Arghyrou and Tsoukalas (2011), since these authors used the literature on currency crises to analyze the Greek sovereign debt market, and concluded that there was a high risk of financial contagion to other peripheral countries in the Euro zone.

In the second branch we consider the study of Bolton and Jeanne (2011). These authors proposed a theoretical model that showed the possibility of contagion in sovereign debt crises through an integrated banking system. The authors also showed how a sovereign debt crisis in one country may be resolved by a combination of bailouts by the other countries in a monetary union and fiscal adjustments in the distressed country.

The studies of the third branch are more common. Missio and Watzka (2011), using DCC models (dynamic conditional correlation models) analyzed the dynamics of the correlations between the Greek sovereign debt yields and the sovereign debt yields of Austria, Belgium, Italy, the Netherlands, Portugal and Spain. The authors concluded for the presence of financial contagion in the sovereign debt markets of Belgium, Italy, Portugal and Spain.

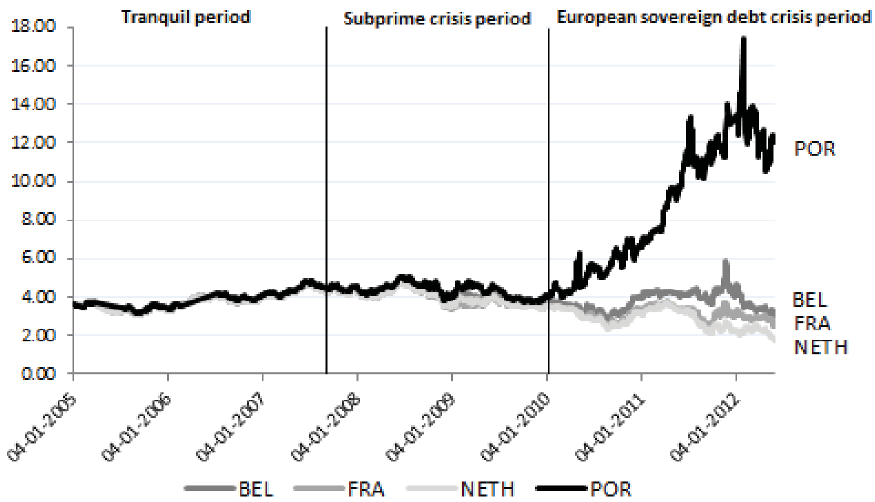
Andenmatten and Brill (2011), using the methodology proposed by Forbes and Rigobon (2002) and Dungey et al. (2005), analyzed the existence of contagion in the CDS premiums for a set of 39 countries, in the context of the 2010 European sovereign debt crisis, and concluded that, for European countries, there was evidence of contagion and of mere interdependence.

Constâncio (2012) stated that contagion played a crucial role in exacerbating the sovereign debt problems in the Euro zone, and therefore the competent authorities should focus on policies to contain the contagion. The author studied spreads between several sovereign debts ("Sovereign-Sovereign") and between sovereign and banks debts ("Sovereign-Bank"). In the case of "Sovereign-Sovereign" spreads, the author noted that there was contagion from the Greek debt yields to the yields of other countries, although the intensity of contagion differed across countries. For instance, for France the contagion effects were reduced, while in the cases of Italy, Ireland, Portugal and Spain, the contagion effects were significant. As for the case of "Sovereign-Bank", the author noted that since the beginning of April 2011 the CDS spreads on the debt of France, Greece, Italy, Ireland and Portugal, explained the increased variance of CDS spreads on the debt of some banks like Crédit Agricole and Société Générale. The author concluded that the contagion of the sovereign debt markets to banks became more significant during the second half of 2011.

Mink and Haan (2012), using an event study methodology inspired by the works of Kho et al. (2000) and Brewer III et al. (2003), analyzed the impact of news on Greece and news about the bailout of Greece in stock prices of 48 European banks, during 2010. The authors concluded that news on the bailout of Greece had a statistically significant impact on the banks stock prices, and suggested that the explanation for such findings could be related to the fact that markets consider the news about the bailout of Greece as a sign that the governments of European countries wanted to use public funds to combat the financial crisis. Furthermore, the authors found that the prices of sovereign bonds of Ireland, Portugal and Spain reacted simultaneously to news about Greece and to news about the bailout of Greece. Thus, the results suggested the existence of financial contagion in stock prices of European banks and sovereign debt markets of Ireland, Portugal and Spain.

Kizys and Pierdzioch (2011) are among the few authors who addressed the issue of financial contagion in stock markets in the context of the 2010 sovereign debt crisis. The authors used the model of speculative bubbles suggested by Wu (1995, 1997) to assess whether there was market contagion from Greek stock market to other stock markets in European countries. The authors found out that the news of speculative bubbles in the Greek stock market caused movements in speculative bubbles in the stock markets of Italy, Ireland, Portugal and Spain, and concluded that speculative movements in Greek stock market had the potential to spread in a contagious way to the stock markets of European countries with high levels of sovereign debt.

Our study also provides some evidence on this latter aspect. In our sample there are countries that investors see as not having unsustainable levels of sovereign debt (Belgium, France and the Netherlands), and there is a country seen as having worrying levels of sovereign debt, Portugal. This perception of investors can somehow be inferred by viewing the evolution of sovereign debt yields traded in the secondary market, as shown in Figure 1.



Source: Bloomberg.

Fig. 1. 10 years sovereign debt yields

Figure 1 shows that the levels of debt yields of Belgium, France and the Netherlands, during the sovereign debt crisis, are not very different from the homologous levels of the tranquil period. The same is not valid for Portugal, since the Portuguese debt yields rose significantly during the sovereign debt crisis period.

As we will see in section 3, the results of our study are in line with those reported by Kizys and Pierdzioch (2011), to the extent that the stock market of Portugal − a country with worrying levels of sovereign debt − exhibits signs of contagion. And the stock markets of Belgium, France and the Netherlands – countries with less worrying debt levels – do not exhibit signs of contagion.

In the following section we describe the data and the methodology of our study, which falls within the third branch of the literature on financial contagion and addresses the issue in the context of stock markets.

2. Data and methodology

This study analyzes how the 2010 sovereign debt crisis, which started in Greece, was transmitted to the European NYSE Euronext stock markets. The analyzed time frame is comprised between January

1, 2005 and April 30, 2012, representing a total of 1829 observations for each index, after excluding holidays. Changes in the logarithms of closing daily values of Morgan Stanley Capital International (MSCI) indices[1], denominated in Euro, are used to represent daily returns from stock markets in Belgium, France, Greece, the Netherlands and Portugal.

After filtering the data with ARMA-GARCH models, the series of indices are divided into three parts, representing three distinct periods. The first is the tranquil period, which runs from January 1, 2005 to July 31, 2007, and comprises 645 observations for each index. The second is the period of the subprime crisis, which begins with the bursting of the Subprime bubble on August 1, 2007 (Horta et al., 2010) and ends on December 7, 2009, comprising 585 observations. The third period comprises the sovereign debt crisis, which begins with the Greek crisis on December 8, 2009, and ends on April 30, 2012 – the last date with data collected for this study. The third period comprises 599 observations for each index.

In Table 6 we test the robustness of December 8, 2009 as the date chosen for the beginning of the sovereign debt crisis.

The reason why we divide the data into three distinct periods relates to the fact that our methodology requires a period of calm and a period of crisis. As the period immediately prior to the sovereign debt crisis is also a crisis period (the subprime), thus dividing the data in this way, we can obtain an effective tranquil period (the same used by Horta et al., 2012) to be compared with the period of the sovereign debt crisis. Figure 1 depicts the division of the three periods.

Despite the generalization of the concept of contagion, there is no consensus on its definition. The various definitions are adopted depending on the nature of concrete studies. For example, Pericoli and Sbracia (2003) or Constâncio (2012) refer to several different definitions commonly used in the literature. In this study, we adopt the definition of "shift-contagion" proposed by Forbes and Rigobon (2002, p. 2223): "a significant increase in cross-market linkages after a shock to an individual country (or group of countries)".

The word "shift" is associated with the change (increase) in correlations between markets. From a practical standpoint, it is considered that the stock markets are facing contagion when the correlation *lato sensu* between the returns of the indices experience a statistically significant increase between the two periods.

The comparison between the two relevant periods is performed after evaluating for each period the distribution functions for the following pairs of indices: Greece-Belgium, Greece-France, Greece-Netherlands and Greece-Portugal. We follow the copula theory and the maximum likelihood approach for this purpose.

The concept of copula was first introduced in finance by Embrechts et al. (1999) and refers to the joint distribution function of random variables, which characterizes the structure of dependence between variables (the so-called marginal variables).

Authors such as Hu (2006), Rodriguez (2007), Costinot, Roncalli and Teiletche (2000) or Embrechts, Lindskog and McNeil (2003) have suggested the use of copulas for analyses of financial contagion, rather than the usual Pearson's linear correlation coefficient, which is only valid for normal distributions, as emphasized by Embrechts et al. (1999) and Embrechts et al. (2003). Although the Pearson's coefficient is consistent with the definition of contagion proposed by Forbes and Rigobon (2002), it could suffer from some methodological problems, as highlighted by Forbes and Rigobon (2002) or Corsetti et al. (2010). This coefficient positively depends on the volatility of asset returns, and since in times of crisis there is usually an increase in the volatility of asset returns series, this means that the linear correlation coefficient could produce a bias that can lead to erroneously conclude for the existence of contagion, when what in fact exists is a mere reflexing of the interdependence between assets. Rachev et al. (2005) describe the following three advantages of copulas over the Pearson's correlation coefficient. First, the nature of dependency that can be modeled is more general. In comparison, only linear dependence can be explained by the Pearson's correlation coefficient; second, the dependence of extreme events might be modeled, using the copula asymptotic tail coefficients; third, copulas are indifferent to continuously increasing transformations of the marginal variables. This is not valid for the Pearson's coefficient, unless the transformations are linear[2].

[1] Bloomberg tickers: MXBE Index, MXFR Index, MXGR Index, MXNL Index and MXPT Index.

[2] Rachev et al. (2005) provide the following example to stress that the Pearson's correlation coefficient is not invariant under nonlinear strictly increasing transformations: "Assume that X and Y represent the continuous return (log-return) of two financial assets over the period $[0, t]$, where t denotes some point of time in the future. If you know the correlation of these two random variables, this does not imply that you know the dependence structure between the asset prices itself because the asset prices (P and Q for asset X and Y, respectively) are obtained by $P_t = P_0 e^X$ and $Q_t = Q_0 e^Y$. The asset prices are strictly increasing functions of the return but the correlation structure is not maintained by this transformation. This observation implies that the return could be uncorrelated whereas the prices are strongly correlated and vice versa".

Thus, instead of using the linear correlation coefficient to measure contagion, we estimate several copula models and then extract the Kendall's tau statistic (τ) − a measure of global association between variables, which is invariant under nonlinear strictly increasing transformations of the marginal variables. We use the Kendall's tau to measure the existence of contagion, comparing the evolution of this statistic between the tranquil and the crisis period (see Horta et al., 2010). If a statistically significant increase of the Kendall's tau is observed, we conclude for the existence of contagion.

In addition to global measures of dependence, copulas also allow extracting measures of local dependence. This is the case of the lower asymptotic tail coefficient (λ_L) and upper asymptotic tail coefficient (λ_U), which provide information on the dependence of the marginal variables in the extremes of the bivariate distributions. For example, using these asymptotic coefficients, we can measure the probability of two indices simultaneously experiencing high decreases or high increases. For technical details on the copula theory, see Nelsen (2006), Schmidt (2006) or Trivedi and Zimmer (2005), among others.

The method we propose for measuring contagion can be summarized in four following steps (Horta et al., 2010).

Step 1. With the purpose of removing autoregressive and heteroskedastic effects from the series of indices, ARMA-GARCH models are estimated. The standardized residuals, here denominated as filtered returns, are recuperated and the respective means and variances are checked for time independence.

Step 2. The series of the filtered returns are divided into two periods, one of calm and another of crisis. Assuming the series are iid, the parametric distribution functions for both periods are estimated by maximum likelihood. Gaussian, *t*-Student, logistic and Gumbel (extreme values) functions are estimated and the Akaike information criterion (AIC) is used to select the most appropriate.

Step 3. The marginal distributions selected in step 2 are used to estimate the copulas by maximum likelihood and the AIC is again used to select the most adequate copula. Pure and mixed copulas are estimated. The former are Clayton, Gumbel, Frank, Gaussian and *t*-Student and the mixed copulas are the Clayton-Gumbel, Gumbel-Survival Gumbel and Clayton-Gumbel-Frank.

The measures λ_U, λ_L and τ are computed using the estimated copulas.

Step 4. Implementation of the bootstrap technique referred by Trivedi and Zimmer (2005, p. 59) to calculate the variance-covariance matrix V of the parameters and other indicators associated to the copulas selected in step 3. The bootstrap technique consists of:

1. Obtaining the marginal distributions' vector of parameters ($\hat{\beta}_1$ and $\hat{\beta}_2$) and the vector of the copulas' dependence parameters ($\hat{\theta}$), by IFM[1] methodology. The global parameters' vector is defined as $\hat{\Omega} = (\hat{\beta}_1, \hat{\beta}_2, \hat{\theta})'$.
2. Randomly drawing a sample of observations (with replacement) from the original data.
3. Using the randomly drawn sample to re-estimate β_1, β_2 and θ, by IFM, and storing the values.
4. Repeating (2) and (3) R times and denoting each estimated parameter as $\hat{\beta}_1(r)$, and $\hat{\theta}(r)$ for the r^{th} re-estimation. The global parameters' vector is identified as
$$\hat{\Omega}(r) = (\hat{\beta}_1(r), \hat{\beta}_2(r), \hat{\theta}(r))'.$$
5. The standard errors for the estimated parameters are the squared roots of the elements in the main diagonal of matrix V, estimated as follows:
$$\hat{V} = R^{-1}\sum_{r=1}^{R}(\hat{\Omega}(r) - \hat{\Omega})(\hat{\Omega}(r) - \hat{\Omega})'.$$

The Kendall's τ, estimated in step 3, is the basis for the two tests of contagion developed in this paper. The same bootstrap procedure, used to obtain standard errors of the dependence parameters, is used to obtain standard errors for the various test statistics. The first of such tests assesses the existence of contagion by checking whether dependence between the stock indices increases from the pre-crisis to the European sovereign debt crisis period. This test's null hypothesis is the absence of contagion:

$$\begin{cases} H_0 : \Delta\tau(i) = \tau_{crisis}(i) - \tau_{calm}(i) \leq 0 \\ H_1 : \Delta\tau(i) = \tau_{crisis}(i) - \tau_{calm}(i) > 0 \\ i = \text{Bel, Fra, Neth, Por} \end{cases} \quad (7)$$

Note that $\tau_{crisis}(i)$ is the global dependence measure between the Greek stock market index and the index of stock market i, for the crisis period and $\tau_{calm}(i)$ has the same meaning, but refers to the tranquil period; $\Delta\tau(i)$ represents the increase in the global dependence measure between the Greek index and the index of market i, from the tranquil to the crisis period.

[1] IFM (Inference Functions for Margins) is the name proposed by McLeish and Small (1998) for the two-step estimation method of the copula parameters. The first step consists in estimating the parameters of the marginal distributions (which we do in step 2) and use the parameters later in the estimation of the parameters of the copula − the second step. One advantage of this method is the possibility to previously testing the goodness of fit of the marginal distributions.

The second test evaluates whether the stock markets in the sample were most affected by the subprime crisis or by the European sovereign debt crisis. Accordingly, if the stock markets data reflect the fact that the subprime crisis was most contagious, the increase in dependence between the US market and each European market index should be stronger than the increase in dependence between the Greek market index and each European market index, from the calm to the respective crisis period (data relating to the subprime crisis are obtained from Horta et al., 2012).

$$\begin{cases} H_0 : \Delta\tau_{Subprime-Debt}(i) = \left(\tau_{crisis}^{Subprime}(i) - \tau_{calm}^{Subprime}(i)\right) - \left(\tau_{crisis}^{Debt}(i) - \tau_{calm}^{Debt}(i)\right) \le 0 \\ H_1 : \Delta\tau_{Subprime-Debt}(i) = \left(\tau_{crisis}^{Subprime}(i) - \tau_{calm}^{Subprime}(i)\right) - \left(\tau_{crisis}^{Debt}(i) - \tau_{calm}^{Debt}(i)\right) > 0 \\ i = \text{Bel, Fra, Neth, Por} \end{cases} \quad (8)$$

$\tau_{crisis}^{Subprime}(i)$ is the global dependence measure between the US market index and the index of market *i*, for the subprime crisis period, and $\tau_{calm}^{Debt}(i)$ refers to the global dependence measure between the Greek market index and the index of market *i*, for the calm period. The superscripts "Subprime" and "Debt" refer to the subprime crisis and to the European sovereign debt crisis, respectively.

The results of the estimation process described in steps 1 to 4 and of the two tests of contagion depicted above are presented in the following section.

3. Results and discussion

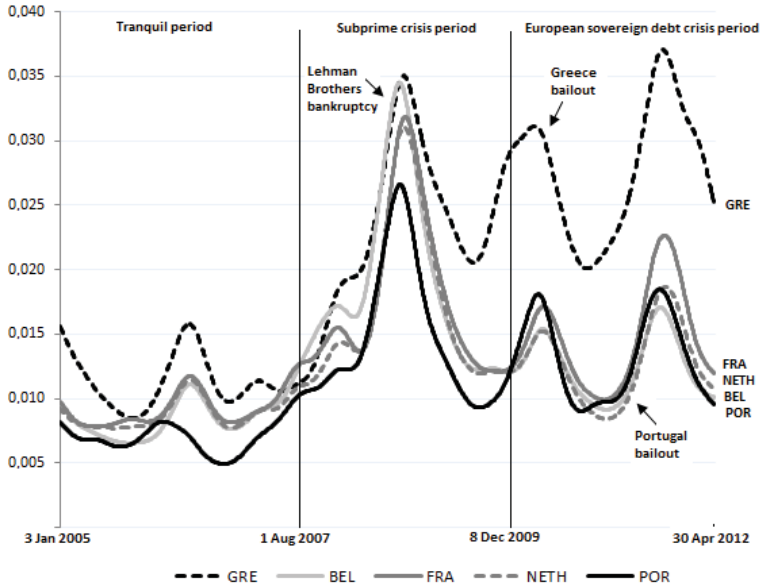
After confirming, with Ljung-Box-Pierce and ARCH of Engle tests, that the series of indices' returns display evidence of time dependence, both in mean and in variance, ARMA models are selected for the average return of each index, subsequently estimated by maximum likelihood, along with GARCH models for the respective variances. Table 1 shows the estimated ARMA-GARCH models[1].

Table 1. Estimated models for the series of indices

Index	Model	Log likelihood
GRE	AR(1), AR(2)-GARCH(1,1)	4740.2
BEL	GARCH(1,1)	5555.5
FRA	ARMA(1,1)-GARCH(1,1)	5441.4
NETH	GARCH(1,1)	5574.7
POR	GARCH(1,1)	5820.2

Note: After converting the raw data into logarithmic returns, ARMA-GARCH models were used to model the mean and variance of the series of logarithmic returns.

The trend of the conditional volatility of filtered returns, for the three analyzed periods, obtained with the Hodrick-Prescott's filter with a smoothing parameter of 1.000.000, is displayed in Figure 2 (for more details see Horta et al., 2010).



Note: This figure graphs the conditional volatility of filtered returns' trends for stock indices of the five countries in the sample, in three distinct periods. These series were obtained after ARMA-GARCH models estimation.

Fig. 2. The trend of the conditional volatility of filtered returns

[1] We performed an alternative exercise to verify that the data filtering method has no influence on the results we obtain. As an example, for the case of Portugal and Greece, instead of splitting the data into three sub-periods after filtering first, we first split the data in the three sub-periods and then apply the filter separately to each sub-period. We found that the conclusions of the contagion tests remain unchanged.

Figure 2 shows that the stock indices volatility increases significantly during the subprime crisis. Excluding the case of Greece, all markets experienced a greater volatility during the subprime crisis. The bankruptcy of Lehman Brothers coincides with the highest peak of volatility. The Greek index reaches the highest volatility in the sovereign debt crisis period.

These data confirm one of the stylized facts of the transmission of shocks in stock markets, described by Corsetti et al. (2010): the volatility of returns increases during financial crises. For this reason, as explained in section 2, using the linear correlation coefficient to measure the contagion could produce biased results, hence our preference for copula models.

Following the procedure described in step 2, the marginal distributions are estimated by maximum likelihood and the most adequate distribution, within a set of Gumbel, Gaussian, logistic and *t*-Student distributions, is selected with the AIC. Table 2 contains the selected functions.

Table 2. Distribution functions for the series of the filtered returns

Pre-crisis period	Selected distribution	Log likelihood	AIC	μ-location parameter (std. error)	σ-scale parameter (std. error)
GRE	Logistic	869.2	-1734.4	0.0354 (0.0361)	0.5252 (0.0171)
BEL	Logistic	840.2	-1676.4	0.0160 (0.0340)	0.4983 (0.0164)
FRA	Logistic	851.3	-1698.6	0.0227 (0.0346)	0.5071 (0.0167)
NETH	Logistic	847.5	-1691.0	0.0250 (0.0341)	0.5013 (0.0166)
POR	Logistic	838.1	-1672.2	0.0188 (0.0334)	0.4922 (0.0163)
Crisis period	Selected distribution	Log likelihood	AIC	μ-location parameter (std. error)	σ-scale parameter (std. error)
GRE	Logistic	860.4	-1716.8	-0.1496 (0.0405)	0.5708 (0.0194)
BEL	Logistic	849.4	-1694.8	-0.0381 (0.0397)	0.5595 (0.0190)
FRA	Logistic	860.3	-1716.6	-0.0578 (0.0405)	0.5707 (0.0195)
NETH	Logistic	853.2	-1702.4	-0.0517 (0.0400)	0.5637 (0.0192)
POR	Logistic	862.0	-1720.0	-0.0774 (0.0409)	0.5750 (0.0195)

Note: These are the selected distribution functions for the marginal.

The logistic distribution is chosen for all indices, suggesting the existence of heavy tails in the series of filtered returns, as the logistic distribution shows heavier tails than those of the Gaussian distribution. Mandelbrot and Hudson (2004) draw attention to the possibility of underestimating the risk of financial assets if the assumption of the Gaussian model used in the current orthodox financial theory is not abandoned.

The univariate distributions are used to estimate the copula models for the pairs of indices under observation in this study, following the procedures described in step 3. The selected copulas, in the pre-crisis and in the crisis periods, are displayed in Table 3.

Table 3. Selected copula models

	GRE/BEL	GRE/FRA	GRE/NETH	GRE/POR
Pre-crisis period				
Selected copula	*t*-Student	*t*-Student	*t*-Student	Clayton-Gumbel
Log likelihood	-78.4	-77.6	-63.3	-42.0
AIC	-152.8	-151.3	-122.6	-80.0
Depend. param. (θ1)	0.4397 (0.0251)	0.4420 (0.0262)	0.4163 (0,0240)	0.4017 (0.1150)
Depend. param. (θ2)	-	-	-	1.5409 (0.2855)
Weight param. (ω1)	-	-	-	0.7425 (0.1075)
Weight param. (ω2)	-	-	-	0.2575 (0.1075)
Deg. of freedom (ν)	6.1719 (1.9800)	7.0251 (2.9822)	18.9228 (7.7822)	-
Kendall τ	0.2898 (0.0178)	0.2914 (0.0186)	0.2733 (0.0168)	0.2146 (0.0186)

Table 3 (cont.). Selected copula models

	GRE/BEL	GRE/FRA	GRE/NETH	GRE/POR
Pre-crisis period				
Selected copula	*t*-Student	*t*-Student	*t*-Student	Clayton-Gumbel
Tail λ_U	0.1377 (0.0413)	0.1159 (0.0432)	0.0096 (0.0206)	0.1112 (0.0330)
Tail λ_L	0.1377 (0.0413)	0.1159 (0.0432)	0.0096 (0.0206)	0.1322 (0.0412)
Crisis period				
Selected copula	Gaussian	*t*-Student	*t*-Student	Gaussian
Log likelihood	-41.2	-57.9	-55.2	-49.5
AIC	-80.4	-111.7	-106.3	-97.0
Depend. param. ($\theta 1$)	0.3594 (0.0264)	0.4179 (0.0256)	0.4032 (0.0265)	0.3933 (0.0256)
Deg. of freedom (v)	-	10.2547 (6.2361)	8.8419 (5.2860)	
Kendall τ	0.2340 (0.0180)	0.2745 (0.0180)	0.2642 (0.0185)	0.2573 (0.0177)
Tail λ_U	-	0.0541 (0.0369)	0.0684 (0.0410)	-
Tail λ_L	-	0.0541 (0.0369)	0.0684 (0.0410)	

Notes: Standard errors are in brackets. Symmetric dependence structures: *t*-Student and Gaussian copulas. Left-hand side dependence is more intense: Clayton-Gumbel copula.

The copulas' parameters (θ, v and w), along with rank correlation (τ) and asymptotic tail coefficients (λ_U and λ_L) are shown in Table 3.

Table 3 contains the copulas selected to model the dependence structures between the Greek stock market index and the European stock markets indices in the NYSE Euronext group. In the pre-crisis period the copula model that is chosen more often is the *t*-Student, suggesting that markets generally exhibit symmetry in the bivariate distribution of returns. Only for the case of Portugal a distinct copula is chosen: the Gumbel-Clayton and, in this case, the weight assigned do the Clayton copula is about three times the weight of the Gumbel copula, suggesting a left bias in the returns distribution of the bivariate series GRE/POR. This bias is confirmed by the tail asymptotic coefficients, since (λ_L) is larger than (λ_U) (0.1322 vs. 0.1112).

For the crisis period, the chosen models are the *t*-Student and the Gaussian copulas. Both exhibit symmetry in returns. The major difference between these models is that the Gaussian copula displays null values for the asymptotic tail coefficients, meaning that in these cases the indices evolve independently when significant increases or decreases occur in the market.

Another important aspect that can be seen in Table 3 is the dynamics of the Kendall's tau, from the tranquil to the crisis period. In the case of Belgium, France and the Netherlands, the Kendall's tau decreases, suggesting the absence of contagion in the respective stock markets. For the case of Portugal, the Kendall's tau increases, suggesting the presence of financial contagion.

The existence of contagion is confirmed as the increases in Kendall's tau from the pre-crisis to the crisis period are statistically significant. This evidence is obtained with test 1's results, shown in Table 4. In order to build the probability function for $\Delta\tau$, 1000 replications were performed in the bootstrapping procedure ($R = 1000$). For each replica, the values of $\Delta\tau$ were collected, ordered and used to build a probability distribution function and in the calculus of the *p*-values, considering the absence of contagion as the null hypothesis (H0: $\Delta\tau \leq 0$). The *p*-values are obtained in a unilateral test, reflecting the probability mass to the left of point $\Delta\tau = 0$.

Table 4. Tests of financial contagion

Index	$\Delta\tau$	$\Delta\tau/\tau$	*p*-value	Conclusion
BEL	-0.0558	-19.3%	0.9820	No contagion detected, only interdependence
FRA	-0.0169	-5.8%	0.7500	No contagion detected, only interdependence
NETH	-0.0091	-3.3%	0.6470	No contagion detected, only interdependence
POR	0.0427*	19.9%	0.0570	Contagion detected

For the pairs involving Belgian, French and Dutch indices, the null of no contagion is not rejected, whereas for the Portuguese case rejection occurs at the 10% significance level. These results suggest the existence of financial contagion only in the Portuguese stock market[1].

[1] We performed an alternative exercise to this in order to use a sample composed of contiguous periods. We compared the tranquil period with a turmoil period that encompasses cumulatively Subprime and sovereign debt crisis. The results we have reached (not presented in this paper, but available upon request) give some hints regarding the intensity of the sovereign debt crisis, but do not allow proper isolation of the effects of contagion from the sovereign debt crisis.

As a robustness check exercise, we re-calculate the figures in Table 4 using the Pearson's correlation coefficient (ρ) instead of the Kendall's tau (τ). The conclusions we reached remain unchanged, although with slightly different levels of statistical significance.

Kizys and Pierdzioch (2011) also concluded that the Portuguese stock market showed signs of contagion in the context of the sovereign debt crisis (as the markets of Italy, Ireland and Spain). Our results and those of Kizys and Pierdzioch (2011) suggest that the stock markets of the countries experiencing the most serious sovereign debt problems appear to be most affected by the crisis, showing signs of contagion.

Finally, the results of test 2 are presented in Table 5. Horta et al. (2010) and Horta et al. (2012) found signs of contagion in the European stock markets of the NYSE Euronext group in the context of the subprime crisis. In test 1 of this study we found that only the Portuguese stock market exhibits signs of contagion in the context of the sovereign debt crisis, so it is expected that the results of test 2 indicate that the subprime crisis was most severe for the stock markets than the 2010 sovereign debt crisis.

Table 5. Tests of intensity difference of subprime and European debt crises

$\Delta\tau_{Subprime\text{-}Debt}(i)$	p-value	Conclusion
$\Delta\tau_{Subprime\text{-}Debt}$(BEL) 0.1587***	0.000	Subprime crisis more is intense than debt crisis
$\Delta\tau_{Subprime\text{-}Debt}$(FRA) 0.1433***	0.000	Subprime crisis more is intense than debt crisis
$\Delta\tau_{Subprime\text{-}Debt}$(NETH) 0.1286***	0.000	Subprime crisis more is intense than debt crisis
$\Delta\tau_{Subprime\text{-}Debt}$(POR) 0.0887***	0.007	Subprime crisis more is intense than debt crisis

Note: *** Means significance at 1% level.

The positive values of the statistics in Table 5 confirm that for all countries in the sample, the subprime crisis was actually more severe than the sovereign debt crisis. The null hypothesis of equal intensity of contagion is rejected in all cases with a significance level of 1%. The tests performed in this section show some evidence that the sovereign debt crisis is not as significant in terms of contagion to the stock markets as the subprime crisis[1]. Perhaps the fact that the subprime crisis exhibits a more global impact when compared to the sovereign debt crisis, may somehow contribute to the justification of this result. Securities regulators may therefore worry less and take less restrictive measures to contain contagion in the stock markets when facing a debt crisis with these features.

We stress the fact that in the context of the subprime crisis, securities regulators have taken some measures to contain the signs of contagion in stock markets (e.g. imposing limits on short selling). The US Securities and Exchange Commission (SEC) was pioneer in this respect, and issued a release note during the peak of the crisis, prohibiting the short selling of securities of financial firms. In that note, the SEC invoked the public interest and the protection of investors to maintain fair and orderly markets in the context of the financial crisis[2].

Finally, Table 6 compares December 8, 2009 with two alternative dates to mark the beginning of the sovereign debt crisis. One of the alternative dates is October 20, 2009 (Andenmatten and Brill, 2011). On this day, the Greek government announced irregularities in the Greek public debt statistics. The other date is December 16, 2009 (Tamakoshi, 2011), a relevant day because it witnessed Standard and Poor's cut of the rating of Greek debt from 'A1-' to 'BBB +'.

Table 6. Sensitivity analysis to the dating of the sovereign debt crisis

		Sovereign debt crisis		
		This study dating (Dec 8, 2009)	Tamakoshi (2011) dating (Dec 16, 2009)	Andenmatten and Brill (2011) dating (Oct 20, 2009)
GRE/BEL	Selected copula	Gaussian	Gaussian	Gaussian
	Kendall τ	0.2340	0.2324	0.2363
GRE/FRA	Selected copula	t-Student	t-Student	t-Student
	Kendall τ	0.2745	0.2723	0.2740
GRE/NETH	Selected copula	t-Student	t-Student	t-Student
	Kendall τ	0.2642	0.2615	0.2644
GRE/POR	Selected copula	Gaussian	Gaussian	Gaussian
	Kendall τ	0.2573	0.2547	0.2569

[1] As we did with respect to Table 4, we also performed a robustness check exercise by re-calculating the figures in Table 5 using the Pearson's correlation coefficient (ρ) instead of the Kendall's tau (τ). The conclusions we reached remain unchanged, reinforcing the results we obtained.

[2] "Given the importance of confidence in our financial markets as a whole, we have become concerned about recent sudden declines in the prices of a wide range of securities. Such price declines can give rise to questions about the underlying financial condition of an issuer, which in turn can create a crisis of confidence, without a fundamental underlying basis. This crisis of confidence can impair the liquidity and ultimate viability of an issuer, with potentially broad market consequences" (SEC, 2008).

Table 6 shows that the date used in this study (December 8, 2009) is robust because the chosen copula models remain unchanged and the estimated Kendall's tau statistics are virtually identical.

Conclusions

The copula theory was used in this study to assess financial contagion from the Greek stock market to the European stock markets in the NYSE Euronext group, in the context of the 2010 European debt crisis. The period of analysis extended from January 2005 to July 2012 and was divided into three sub-periods: one of tranquility and two of turmoil, respectively corresponding to the 2008 financial crisis and to the 2010 European sovereign debt crisis. We analyzed the dependence structures between the representative index of the Greek stock market and the representative indices of each European stock market of the NYSE Euronext group, for the tranquil period and for the period of the sovereign debt crisis.

Maximum likelihood procedures were employed to estimate distribution functions for the individual indices, copula models and the parameters to be used in the tests of contagion. In such tests, attention was focused on the Kendall's τ obtained from the copulas. The Kendall's τ was chosen as a measure of global dependence over the more commonly used Pearson's linear correlation coefficient.

Two empirical tests of contagion were performed. The first test suggests that contagion exists only in the Portuguese stock market. The other three markets in the sample show interdependence but no contagion. The second test shows that the contagion effects of the 2008 financial crisis are clearly more intense than those caused by the 2010 sovereign debt crisis.

The results suggest that the sovereign debt crisis is not as significant in terms of contagion to the stock markets as the subprime crisis. Securities regulators may therefore take less stringent measures to contain contagion in the stock markets when facing a debt crisis with similar features.

Regarding the markets analyzed in this study, the results of the tests provide more useful information to securities regulators. In particular they suggest that only the Portuguese case justifies more stringent measures to contain contagion. Belgian, French and Dutch regulators could impose less stringent measures than those that could be conceived for Portugal.

The study also suggests that stock markets of countries where sovereign debt is not under market pressure, exhibit no signs of contagion. This is the case of stock markets in Belgium, France and the Netherlands. On the contrary, Portugal displays signs of contagion in the respective stock market. These results are in line with those reported by Kizys and Pierdzioch (2011).

Finally, in addition to the specific object of this analysis, the evidence supplied by the copula models and by the respective tests of contagion may be useful in other contexts. For instance, it may be interesting for those involved in risk evaluation or in portfolio diversification that not only the strength of the links between markets but also their nature has changed following the crisis.

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