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Stock market interdependencies

Evidence from the Eurozone´s southern periphery before
and after the outbreak of the European debt crisis

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Abstract

Recent events in the Eurozone´s southern periphery have directed much interest to the region but only a limited number of studies have targeted the market interdependencies among these counties. This thesis examines the interdependencies among the stock markets in the Eurozone´s southern periphery, before and after the outbreak of the European debt crisis. By applying the Johansen test of cointegration and the DCC-MGARCH model, both the long-run and short-run interdependencies are examined. The data employed consist of daily stock market index return series from Greece, Italy, Portugal and Spain, covering the period January 1, 2001 to May 10, 2013. This period is further decomposed into two subsamples to enable an analysis of how the European debt crisis has impacted the interdependencies in the region: the pre-crisis period ranges from January 1, 2001 to October 15, 2009 and the post-crisis period from October 16, 2009 to May 10, 2013. The result shows evidence of stock market interdependencies in the Eurozone´s southern periphery, particularly in the form of short-run volatility correlation. The result also indicates that the outbreak of the European debt crisis has affected the volatility correlation in the region. The main finding is that the volatility correlation has increased since the outbreak of the European debt crisis between all pairwise comparisons except for these involving the Greek market. The fact that interdependencies exist among all markets in the region is imperative for investors and policy makers and highlights the importance of sound portfolio management and regulatory policies.

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1. Introduction

Financial integration, both domestically and internationally, has increased vastly last decades. Technological progresses have facilitated transactions of capital and transmissions of news, liberalizations of capital movements have increased cross-border flow of capital, and market deregulations have harmonized the structure of financial markets worldwide (see e.g. Mathur and Subrahmanyam, 1990; Booth, Martikainen and Tse, 1997; Kearney and Lucey, 2004; Deehani and Moosa 2006; Bhar and Nikolova, 2009; Ehrmann, Fratzscher and Rigobon, 2011). In particular, Europe has experienced a time of extraordinary economic and financial integration. The initiation of the European Union (EU) ensued free movements of people, goods, services and capital among the member states as well as established supranational institutions including the European Commission (EC) and the European Central Bank (ECB) and the introduction of the European Monetary Union (EMU) synchronized member states monetary policies, created a single financial market as well as eliminated exchange rate barriers (see e.g. Billio and Pelizzon, 2003; Skintzi and Refenes, 2006; Bartram, Taylor and Wang, 2007; Christensen, 2007; Balli, 2009, Koulakiotis, Dasilas and Papasyriopoulos, 2009; Adel and Salma, 2012).

Most researchers agree that the process of financial integration stipulates interdependencies among financial markets. Market interdependencies refer to comovements of markets, either across borders or across equity classes. A bulk of the literature indicates that financial markets move together over time and that interdependencies increase in times of financial turmoil (see e.g. Koutmos and Booth, 1995; Booth et al, 1997; Kanas, 1998; Kanas and Kouretas, 2001; Shintzi and Refenes, 2006; Chiang, Jeon, and Li, 2007; Boubaker and Jaghoubi, 2011; Zhou, Zhang, and Zhang, 2012). Much literature has also revealed that the interdependency tend to be time-varying, with some periods of abnormally large volatility, and that mean return and volatility tend be more correlated in these periods (see e.g. Hamao, Masulis and Ng, 1990; Fernandez-Izquierdo and Lafuente, 2004; Bauwens, Laurent, and Rombouts, 2006; Drakos, Kouretas and Zarangas, 2010).

Understanding the market interdependency is important for a number of reasons. Firstly, it has imperative implications for portfolio managers making asset allocation decisions. The capital asset market theory suggests that international diversification reduces the idiosyncratic risk. However, a higher degree of comovements among the international markets negatively affects the scope of cross-border diversification. Secondly, interdependencies among financial markets have significant consequences for policy makers and regulators working to stabilize financial markets. The risk of financial contagion has been fueled by an increasingly globalized world. To ease these contagious effects policy-makers and regulator have to assess the market interdependencies in order to implement mechanisms that enable effective monitoring of international capital flows. Thirdly, to comprehend the volatility correlations is essential for investors because volatility largely affects the pricing of derivate securities and the calculation of risk premiums (see e.g. Niarchos, Tse, Wu, and Young, 1999; Ng, 2000; Gagnon and Karolyi, 2006; Shintzi and Refenes, 2006; Badhani, 2009; Drakos et al, 2010; Ehrmann et al, 2011).

Although recent events in the Eurozone´s southern periphery[1] have directed much interest to the region only a limited number of studies have targeted market interdependencies in these countries. Niarchos et al (1999) investigated interdependency between the U.S and the Greek stock market between January 1993 and September 1997 without finding any evidence of comovements, neither in the long-run nor in the short-run, and Richards (1995) examined cointegrations among several stock markets, including the Italian and the Spanish, between 1974 and 1994, without identifying any long-run relationship. Contrarily, Glezakos, Merika and Kaligosfiris (2007), covering the period from 2000 to 2006, evidenced stark unidirectional transmission of innovations from the U.S and the German stock markets to the Greek, the Italian and the Spanish stock markets. The authors also observed that the Greek stock market was influenced by the movements in the Italian and Spanish stock markets. Furthermore, Koulakiotis et al (2009) investigated volatility transmission between portfolios of cross-listed stocks within three European regions and one of their findings was that the Belgian, Dutch and French stock markets were the major sources of volatility to the Italian and Spanish stock markets. In a recent paper, Adel and Salma (2012) studied the existence of financial contagion in the Euro area using stock market data from 2007 to 2011. The authors revealed that the interdependencies between the Greek stock market and the Italian and the Portuguese stock markets have increased after the outbreak of the European debt crisis. However, Adel and Salma (2012) also proved that the market dependence between the Greek stock market and most of the major stock market in the Eurozone, including the Spanish, has become weaker after the occurrence of the crisis.

The objective of this thesis is to investigate the interdependencies among the stock markets in the Eurozone´s southern periphery, from January 1, 2001 to May 10, 2013, using the Johansen´s test of cointegration and the dynamic conditional correlation multivariate general autoregressive conditional heteroskedasticity (DCC-MGARCH) model. More precisely, this study targets the following research questions: (1) Are there any interdependencies among the stock markets in the Eurozone´s southern periphery? (2) If yes, has the European debt crisis affected the strength of the short-run dynamic linkages in the region? The application of the Johansen test of cointegration and the DCC-MGARCH model enable an examination of the long-run cointegration relationships and the short-run dynamic linkages, respectively, and the chosen time period allows for an analysis of the implications the outbreak of the European debt crisis have had on the short-run dynamic linkages in the region.

The area of research is highly relevant because of current development in the Eurozone´s southern periphery, where a shock in one country's stock market may severely impact the other countries' stock markets. This thesis contributes to the literature on financial interdependencies in several respects. Firstly, this study explores how the stock markets in the European southern periphery move together. Only a few studies have targeted the stock markets in the region and none has explicitly focused on the comovements among them. Secondly, by using up-to-date observations, this thesis captures the effects of recent events in the Eurozone´s southern periphery. The inclusion of data up to May 10, 2013 allows for a rigorous analysis of how the European debt crisis has affected the market dependencies in the region. Thirdly, this study provides results on both the long-run cointegration relationships and the short-run dynamics in the European southern periphery. This contrasts with

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[1] Refers to Greece, Italy, Portugal and Spain.

much of the previous literature, which primarily has focused on the short-run dynamics of interdependencies. Lastly, the empirical result obtained can provide a framework for policy makers, regulators and portfolio managers to curb potential contagious effects within and outside the region.

The remainder of this study proceeds as follows. Section 2 gives a review of the literature and theory. Section 3 introduces the methodology framework used to investigate the research questions of this thesis. Section 4 describes the data and provides preliminary results. Section 5 presents the empirical results and Section 6 provides the result form the robustness tests. Section 7 summaries the findings and concludes the study.

2. Literature and theory review

Standard financial theory suggests that financial time series, including stock return series, follow a stochastic process where the current value of a variable is composed of the past value plus an error term. The error term is defined as white noise, which assumes a mean of zero and a variance of one. The movements in the variable are therefore believed to be completely random. However, much literature has showed evidence of serial correlation in both the return and the error term, which means that financial time series act as non-stationary processes with conditional heteroskedastic error progressions. The movements in the variable are not only dependent on its own past values, however. It is also well-documented in financial literature that financial time series move together over time.

Studying comovements across financial markets is an essential issue for portfolio managers, investors and policy makers and the process of international integration of financial markets has received much attention in financial literature. Early papers, including Grubel (1968) and Levy and Sarnat (1970), focused on the prospective gains associated with international diversification. Both Gruble (1968) and Levy and Samat (1970) proved that U.S investors could achieve a better risk-to-reward ratio by internationally diversifying their stock portfolios. Levy and Samat (1970) additionally noticed that a stock portfolio weighted towards countries exhibiting weak ties with the U.S economy increased the scope of diversification.

The benefits of international diversification, together with liberalization and deregulation of financial markets, have enticed cross-border investments and globalized financial markets. According to Gagnon and Karolyi (2006), this process has increased the financial linkages among seemly unrelated economies and has triggered the contagious effects experienced in times of financial turmoil. Amongst others, Koutmos and Booth (1995) and Kanas (1998) evidenced that the interdependencies between major stock markets increased after the Crash of October 1987, Chiang et al (2007) and Yilmaz (2010) showed that volatility correlation strengthen among Asian equity markets during the East Asian Crisis of 1997, and Boubaker and Jaghoubi (2011) and Zhou et al (2012) demonstrated that financial markets worldwide experienced contagious effects in the outbreak of the Subprime crisis.

Karolyi and Stulz (1996), in an attempt to explain why stock markets move together, found that macroeconomic announcement and shocks in the foreign exchanges and treasury bills markets had no measurable effects on the comovements between the US and Japanese stock market. However, they

showed that shocks in broad market based indices, such as S&P 500 and Nikkei Stock Average, impacted both the persistence and strength of the correlations.

The correlation between major stock markets has also been the main focus in the literature on financial interdependencies. For instance, Eun and Shim (1989) evidenced that the U.S stock market strongly influenced nine other stock markets around the world and Hamao et al (1990) proved that significant volatility spillover transpired from the U.S stock market to the U.K and Japanese stock markets, from the U.K stock market to the U.S and the Japanese stock markets, but not from Japanese stock market to the U.S and the U.K stock markets. The latter result was, however, contradicted in a study by Bae and Karoly (1994), who found strong volatility correlation between the U.S and the Japanese stock market.

Much of the literature on financial comovements in the European region has also addressed the major stock markets. As such, Kanas (1998) evidenced significant reciprocal spillover effects between France and Germany, and between France and U.K, and unidirectional spillover effects from U.K to Germany. Additionally, Billio and Pelizzon (2003) and Bartram et al (2007) investigated whether the introduction of the Euro increased the interdependencies among the Eurozone's stock markets. Billio and Pelizzon (2003) implied that the influences of the German stock market amplified in Eurozone after the launch of the Euro and Bartram et al (2007) noticed a market dependence increase in major European stock markets in the aftermath of the Euro introduction.

Another course of the literature has targeted the interdependencies among regional stock markets. The main finding from these studies is that markets which are geographically close to each other tend to be more correlated. For instance, Janakirmanan and Lamba (1998) discerned that stock markets in the Pacific-Basin region influence one another and Al-Deehani and Moosa (2006) observed significant correlation among three major stock markets in the Middle East. Janakirmanan and Lamba (1998) suggested that their findings were related to home bias[2], while Al-Deehani and Moosa (2006) argued that the increased correlation among the countries in their study was due to the establishment of a common trading platform that facilitated cross-border investment. Furthermore, Johansson and Ljungwall (2008) noticed short-run dynamic linkages among the Greater China´s stock markets, despite significant regulatory impediments that limited cross-border investments, and suggested geographic proximity as a plausible explanation.

Interdependencies are measured in either the long-run, generally in terms of cointegration, or in the short-run, generally in terms of short-run dynamic linkages. The concept of cointegration was first introduced in seminal work by Granger (1981). Granger (1981) suggests that if all variables of a vector time series process exhibit a unit root, there might exist linear combinations without a unit root, and the existence of linear combinations can, in turn, be interpreted as an indication of long-run cointegration relationships between the variables of the vector time series process. In other words, times series are said to be cointegrated if they exhibit an analogous stochastic drift. Mainly three methods, including the Engle-Granger two-step method, the Phillips Ouliaris cointegration test, and the Johansen test of cointegration, are used to test for cointegration. The Johansen test of

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[2] A well-observed tendency that investors prefer investments in their close geographic proximity. See, for instance, Janakirmanan and Lamba (1998) for a more detailed description.

cointegration, developed by Johansen (1988) and (1991), is preferred by economists because this test only includes one step of estimation as well as allows for several cointegrating relationships.

The Johansen test of cointegration has been applied in several studies, including Richards (1995), Niarchos et al (1999), Johansson and Ljungwall, (2008), and Badhani (2009). Richards (1995) using the Johansen test of cointegration to investigate whether there exist long-run relationships among the Japanese, the US, and several European stock markets. The purpose of the study was to empirically test the efficient market theory, which suggests that cointegration is unlikely to be observed. Richards (1995) found no evidence of cointegration and argued that each index series includes country-specific components which cause them to behave differently over time. Niarchos et al (1999), Johansson and Ljungwall, (2008), and Badhani (2009) used the Johansen test of integration to examine the long-run relationship between the Greek and the U.S stock market, the stock markets in Greater China, and the Indian and the U.S stock market, respectively. None of these studies found supporting evidence of cointegration.

Engle (1982), in a seminal work, developed an auto regressive conditional heteroskedasticity (ARCH) methodology to capture financial times series endogenous volatility spillovers. The ARCH methodology was later generalized by Bollerslev (1986) to the generalized ARCH (GARCH) methodology, which also allowed the method to capture the persistence of the endogenous volatility spillovers. In other words, the ARCH and GARCH framework were developed to account for serial correlation in the return and error term of univariate time series. Since much literature has indicated that financial return series move together across markets, Bauwens et al (2006), amongst others, argue that multivariate extensions of the univariate frameworks are more appropriate to examine the behavior of financial time series. The general multivariate GARCH (MGARCH) is, however, considered too flexible for most problems and therefore four alternative models have been developed. As such is the dynamic conditional correlation (DCC) MGARCH[3] model, introduced by Engle (2002). The DCC-MGARCH model, a modification of the constant conditional correlation (CCC) MGARCH model, allows the conditional covariance matrix of the dependent variables to follow a dynamic representation and the conditional mean to follow a vector autoregressive (VAR) representation. The relaxation of the assumption of constant conditional correlation enables the model to capture the well-observed phenomenon of volatility clustering, which means that periods of large swings randomly succeed periods of small swings, and vice versa. Consequently, the model enables estimation of time-varying volatility correlations. Moreover, the VAR representation enables an estimation of mean spillovers since the model fits a multivariate time-series regression of each dependent variable on lags of itself and on lags of all the other dependent variables.

The DCC-MGARCH model is more flexible than the CCC-MGARCH model without including an unreasonable number of parameters. At the same time, the DCC-MGARCH model is more parsimonious than the diagonal vech (DVECH) MGARCH-model. All the conditional correlations follow, however, the same dynamic and that is, according to Bauwens et al (2006), a major weakness of the DCC-MGARCH model.

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[3] Other multivariate extensions of the GARCH framework are the diagonal vech (DVECH) model, the constant conditional correlation (CCC) model, and the varying conditional correlation (VCC) model.

The DCC-MGARCH model is, for instance, applied by Chiang et al (2007) to study the dynamic conditional correlation among nine Asian stock markets, using daily data from 1990 to 2003. Firstly, they found an increased correlation during the East Asian crisis and interpreted this as financial contagion. Secondly, they also found evidence of a continued high correlation in the post-crisis period and interpreted this as herding effects. Chiang et al (2007) conclude their study by casting doubt on the benefits of international diversification.

3. Methodology

The Johansen test of cointegration and the DCC-MGARCH model are used to investigate the research questions of this thesis. The presence of a cointegrating vector can be interpreted as the presence of a long-run equilibrium relationship. Therefore, the Johansen test of cointegration is first employed in its multivariate form to identify whether any long-run cointegrating relationships among the stock markets in the European southern periphery exist. If any cointegrating relationship is discovered, the test is run in its bivariate form for all pairwise combinations. The DCC-model is applied to investigate the short-run dynamics among the four stock markets in the region for the full sample period, for the pre-crisis period, and for the post-crisis period. The two methods are, however, not independent of each other. Any cointegration relationship among the variables needs to be considered when the mean equation in the DCC-MGARCH model is formulated. According to Johansson and Ljungwall, (2008), if all return series are cointegrated, a vector error correction model (VEC) model should be specified for the mean equation. Otherwise, if the return series are not cointegrated, the mean equations should be specified by using a standard vector autoregressive (VAR) model. Furthermore, Niarchos et al (1999) state that the lack of cointegration suggests that if mean spillovers exist, they are, at most, short-run in nature. In other words, the lack of cointegration, but evidence of mean spillovers implies that these are of short-run character.

3.1 Johansen test of cointegration

Test of cointegration is a powerful tool to analyze financial data in order to determine whether time series share an analogous stochastic drift. The Johansen test of cointegration, outlined in Johansen (1995), is an efficient method to examine the cointegration among several time series. The test is preferred by economists because it only includes one step of estimation and allows for several cointegrating relationships.

The Johansen test of cointegration commences with a vector autoregression (VAR) representation of the variables. Each variable is handled symmetrically with an equation explaining its process based on its own past values and the past values of the other variables included in the model. The variables are assumed to be integrated of order one, usually denoted I(1). The VAR p-dimensional process VAR(p), is given by equation (1):

$$y_t = \mu + A_1 y_{t-1} + \cdots + A_p y_{t-p} + \varepsilon_t \hspace{3cm} (1)$$

where y_t is a $n * 1$ vector of the dependent variables; μ is a $n * 1$ vector of constants, and ε_t is a $n * 1$ vector of innovations. This VAR process can be transformed to a vector error correction (VEC) model by using the difference operator: $\Delta y_t = y_t - y_{t-1}$. The VEC model is given by equation (2):

$$\Delta y_t = \mu + \Pi y_{t-1} + \sum_{t=1}^{p-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t \tag{2}$$

where Π and Γ_i are matrixes of variables in accordance with equation (3) and (4), respectively:

$$\Pi = \sum_{i=1}^{p} A_t - I \tag{3}$$

$$\Gamma_i = - \sum_{j=i+1}^{p} A_j \tag{4}$$

The Johansen test of cointegration is essentially a unit root test, which implies that the Π-matrix is the parameter of interest. If the number of cointegration vectors (r) are equal to the number of stationary relationships in y_t (n), i.e. r = n, so the Π-matrix has full rank, then all variables in y_t are stationary. On the contrary, if the Π-matrix has reduced rank, i.e. r < n, then one or more variables in y_t are nonstationary. If the Π-matrix has reduced rank, there are cointegration among y_t; a reduced rank Π-matrix exists of α and β matrixes, each with rank r, such as $\Pi = \alpha\beta'$, where β represents the cointegration vector and α represents the adjustment parameters of the VEC model. A valid cointegration vector will produce a significant non-zero eigenvalue. Consequently, the Johansen test of cointegration solely test the number of non-zero eigenvalues of the Π-matrix to the number of stationary relationships in y_t.

The Johansen test statistic, commonly derived by a trace test[4], is calculated with equation (5):

$$J_{Trace} = -T \sum_{i=r+1}^{n} ln(1 - \widehat{\lambda}_i) \tag{5}$$

where T is the sample size, n is the number of number of stationary relationships in y_t, and λ_i is the real number of eigenvalues. The trace test examines the null hypothesis of r cointegration vectors against the alternative hypothesis of n (full rank) cointegration vectors. The hypothesis test is nested to rank r, where $r = 0, 1, 2 \dots, n - 1$. Thus, the trace statistic should be tested against the critical value for each rank. If the trace statistic is greater than the critical value, the null hypothesis of no cointegrating relationships is rejected. The test procedure begins with the test for no cointegrating relationships and then accepts the first null hypothesis that is not rejected. The first null hypothesis

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[4] An alternative test is the maximum eigenvalue test: $J_{Max} = -T \, ln(1 - \widehat{\lambda}_{r+1})$. The trace test is, however, a more robust test since it processes skewness and excess kurtosis more accurately (see e.g. Luintel and Khan (1999))

that is not rejected specifies the number of cointegrating relationships. The critical value for each rank can be found in Johansen (1995).

The level of integration for each stock market is identified with the Augmented Dickey-Fuller test for unit root, developed by Dickey and Fuller (1979), and the number of lags is selected based on the Schwarz Bayesian information criterion.

3.2 DCC-MGARCH

Multivariate GARCH models allow the conditional covariance matrix of the dependent variables to follow a dynamic representation and the conditional mean to follow a VAR representation. The DCC-MGARCH model, suggested by Engle (2002), has the flexibility of the univariate GARCH models and is less complicated than the general MGARCH models. The DCC-MGARCH model is adopted in this thesis because it enables estimation of time-varying volatility correlations as well as appraisal of mean spillovers. The model is given by equation (6) and (7):

$$y_t = \mu_t(\theta) + \varepsilon_t \tag{6}$$

$$H_t = D_t R_t D_t \tag{7}$$

Equation (6) is the vector stochastic process, where $y_t = (y_{it} \dots y_{nt})$ is a $n*1$ vector of the dependent variables; $\mu_t(\theta) = (\mu_{it} \dots \mu_{nt})$ is a $n*1$ conditional mean vector of y_t, and $\varepsilon_t = H_t^{1/2}(\theta)z_t$, where $H_t^{1/2}$ is a Cholesky factor of the positive definite time-varying conditional covariance matrix H_t, and z_t is a $n*1$ vector of innovations. The conditional variance and the covariance of the error term are assumed to follow an autoregressive-moving-average (ARMA) process. Both H_t and μ_t depends on the independent vector θ, which normally can be split into two disjoint parts, one for H_t, and one for μ_t. To estimate mean spillovers, Equation (6) can be rewritten to a VAR model similar to Equation (1) plus additional exogenous variables for the other return series, or a VEC model similar to Equation (2) plus additional exogenous variables for the other return series. Consequently, the VAR and VEC model fit a multivariate time-series regression of each dependent variable on lags of itself and on lags of all the other dependent variables. The choice of model is dependent on whether it exists cointegrating relationships between the return series or not.

Equation (7) is the DCC estimator, models the volatilities and correlations. $D_t = diag(h_{iit}^{1/2} \dots h_{nnt}^{1/2})$ is a diagonal matrix of square root conditional variance from any univariate GARCH model, such the GARCH(1,1) specification suggested by Bollerslev (1986), defined in accordance with equation (8):

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-1}^2 + \sum_{j=1}^{p} \beta_j h_{t-j} \tag{8}$$

where h_t is the conditional variance, α_i is the ARCH parameters, and β_j is the GARCH parameter. R_t is a $n*n$ time-varying conditional correlation matrix, given by equation (9):

$$R_t = diag\left(q_{iit}^{-\frac{1}{2}} \dots q_{nnt}^{-\frac{1}{2}}\right) Q_t \, diag\left(q_{iit}^{-\frac{1}{2}} \dots q_{nnt}^{-\frac{1}{2}}\right) \qquad (9)$$

where $Q_t = q_{ijt}$ is a $n*n$ time-varying covariance matrix of the standardized residuals, defined by equation (10):

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha \mu_{t-1}\acute{\mu}_{t-1} + \beta Q_{t-1} \qquad (10)$$

where $\mu_{it} = (\mu_{1t}\mu_{2t}\dots\mu_{nt})$ is a $n*1$ vector of standardized residuals, $\bar{Q}$ is a $n*n$ unconditional variance matrix of μ_t, and α and β are nonnegative scalar parameters that satisfy $\alpha + \beta < 1$.

The DCC-MGARCH model proposed by Engle (2002) is a three-step estimation procedure of the time-varying conditional covariance matrix H_t. In the first step, the parameters for each univariate return series are derived, giving the estimates of the square root conditional variance $h_{iit}^{1/2}$. In the second step, the return series standardized residuals μ_{it} are derived from the estimated standard deviation ε_{it} and the estimated square root conditional variances $h_{iit}^{1/2}$ from the first step; that is $\mu_{it} = \varepsilon_{it}/h_{iit}^{1/2}$. The standardized residuals μ_{it} are then applied to equation (10) to estimate the parameters of the conditional variance. In the third step, these parameters are employed to estimate the time-varying conditional volatility correlation matrix R_t. A characteristic element of R_t is of the form: $\rho_{ijt} = q_{ijt}/q_{iit}^{1/2}q_{jjt}^{1/2}$, where $,j = 1,2,\dots,n$, $i \neq j$, and ρ_{ij} is the volatility correlation coefficient. Thus, the volatility correlation coefficient ρ_{ij} can in a bivariate case be expressed by equation (11):

$$\rho_{12t} = \frac{(1 - \alpha - \beta)\bar{q}_{12} + \alpha \mu_{1,t-1}\alpha \mu_{2,t-1} + \beta q_{12,t-1}}{\sqrt{\left((1 - \alpha - \beta)\bar{q}_{11} + \alpha_{1,t-1}^2 + \beta q_{11,t-1}\right)}\sqrt{\left((1 - \alpha - \beta)\bar{q}_{22} + \alpha_{2,t-1}^2 + \beta q_{22,t-1}\right)}} \qquad (11)$$

The DCC-GARCH model in this thesis is estimated using a log likelihood estimator under a multivariate student-t distribution, developed by Bollerslev (1986), which allows for volatility clustering and non-normal distribution. The Schwarz Bayesian information criterion is employed to facilitate the model selection and the diagnostic checking of the level and the squared standardized residuals are used to test the robustness of the chosen models.

4. Data description and preliminary results

The data employed in this thesis consist of daily stock market index return series from Greece, Italy, Portugal and Spain, covering the period January 1, 2001 to May 10, 2013. This period is further decomposed into two subsamples to enable an analysis of how the European debt crisis has impacted the interdependencies in the region: the pre-crisis period ranges from January 1, 2001 to October 15,

2009 and the post-crisis period from October 16, 2009 to May 10, 2013[5]. The models used in the thesis include many parameters and require a large number of observations to yield reliable results. Therefore, to avoid small sample issues in the subsamples, the sample period is chosen to be as long as possible. For the same reason, daily data is used instead of weekly data, although weekly data may be preferable in order to avoid problems related to non-synchronous trading and the day-of-the-week effect[6]. The stock market indices are represented by MSCI´s general index for Greece, Italy, Portugal and Spain, respectively. The data for these index series are collected from DataStream and each includes 3223 observations. The pre- and post-crisis periods are sampled with 2270 and 931 observations for each country. The data is tested and modeled in Stata and the figures and tables are constructed in Excel.

The observations are transformed into logarithmic scale and each index series is plotted against time. The result is demonstrated in Figure 1. The development of the index series over the full sample period diverge significantly, where the Spanish is the upper extreme with a slightly positive return and the Greek is the lower extreme with a sharply negative return. The log-levels of the indices indicate non-stationarity, a well-observed characteristic of stock markets. The indication of non-stationarity increases the likelihood of cointegration among the four return series.
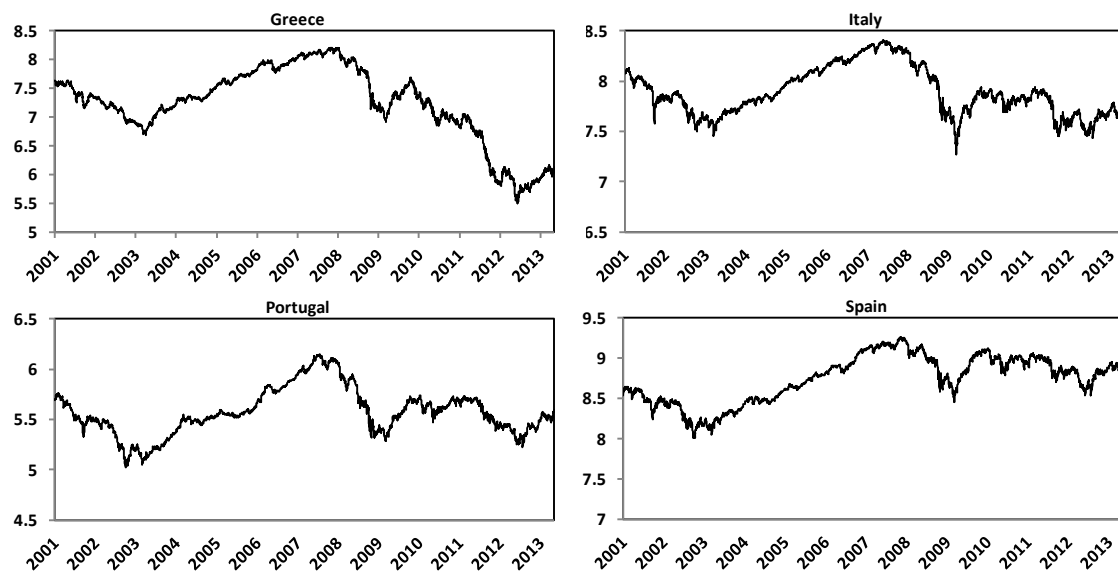

Figure 1: Log-level indices

Figure 2 shows the daily returns for each return series. The rate of return is computed as continuously compounded with $R_{i,t} = 100 * \log(P_{i,t}/P_{i,t-1})$, where $R_{i,t}$ is the continuous compounded return for index i at time t and $P_{i,t}$ is the price level of index i at time t. The continuous compounded return series exhibit no trend, which is an indication of stationarity. However, the volatility seem to be clustered, which means that large swings tend to be followed by large swings and small swings tend to be followed by small swings. The latter is an indication of GARCH effects. Figure 1 and 2 support the sectioning of the subsamples since the period ending in 2009 is characterized by positive returns

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[5] This distinction is employed by Adel and Salma (2012). Low volatility and positive returns characterize the pre-crisis period while high volatility and negative returns characterize the post-crisis period.

[6] The tendency of stocks to perform better on Fridays than on Mondays. See, for instance, Ng (2000) for a more detailed description.

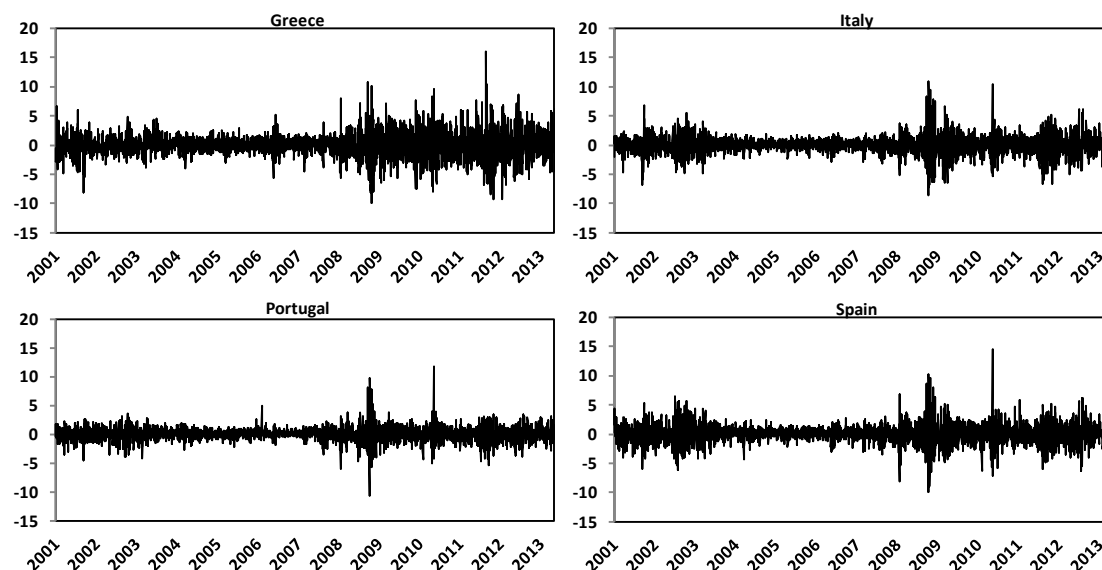and low volatility and the period starting in 2009 is characterized by negative returns and high volatility.

Figure 2: Stock market returns

Table 1 gives the descriptive statistics for the full sample return series. The daily mean returns range from negative 0.0487% in Greece to positive 0.0122% in Spain, while the standard deviations range from 1.1862 in Portugal to 1.9790 in Greece. The latter indicates that the Greek stock market is the most volatile market. Moreover, during the sample period, the Portuguese market has experienced the largest one-day drop in the index, with negative 10.7751%, and the Greek market the largest one-day hike in index, with positive 15.9579%.

The measures for skewness imply that all return series are skewed but in different directions. Italy is negatively skewed, while Greece, Portugal and Spain are positively skewed. A negative skew indicates that negative shocks occur more frequently than positive shocks, while the opposite is true for a positive skew. The measures for excess kurtosis also demonstrate that all return series are leptokurtic, which indicates that large shocks are more frequent than expected in all markets. Most of the measures for skewness and excess kurtosis are statistically significant at 1% level, which means that the null hypothesis of normal distribution can be convincingly rejected for all return series.

The Ljung-Box Q statistic[7] tests for serial correlation up to 40 lags lengths. The results report the Q statistic to be significant at 40 lags, which implies serial correlation in the return and squared return for all return series. The former indicates non-randomness and the presence of ARCH effects in the return and the latter result indicates heteroskedasticity and the occurrence of GARCH effects in the squared returns.

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[7] See Ljung and Box (1978) for a detailed description.

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Table 1: Summary statistics for full sample return series

	Greece	Italy	Portugal	Spain
Observations	3223	3223	3223	3223
Mean	-0.0486591	-0.0109403	-0.0034896	0.0121508
Min	-9.948921	-8.627663	-10.77514	-9.856358
Max	15.95793	10.9855	11.71885	14.52243
Standard deviation	1.978986	1.497252	1.186219	1.599873
Skewness	0.1324514**	-0.0188855	0.0287893	0.1948494**
Excess kurtosis	7.47667**	8.488395**	12.23313**	8.719404**
LB(40)	62.149*	141.98**	86.9892**	117.4862**
LB^2(40)	2271.0451**	3578.1731**	1598.2464**	2128.8817**

Note: Summary statistics for daily return data, covering the period January 1, 2001 to May 10, 2013. Skewness and excess kurtosis test for normal distribution. LB (Ljung-Box statistic) tests for serial correlation in the return and LB^2 tests for serial correlation in the squared return. The number of lags is specified in the parenthesis. The asterisks indicate the statistical significance at 1% (**), and 5% (*) level.

Table 2 presents the descriptive statistics for the two subsamples. The return series in both subsamples have a negative mean return except for the Spanish pre-crisis mean, which yields a positive return. Furthermore, it is clearly shown that the standard deviation in the post-crisis sample is higher than the standard deviation in the pre-crisis sample. This indicates that the outbreak of the European debt crisis has induced larger movements in the returns. Also, the reported standard deviation implies that Portugal's standard deviation is significantly lower than the other countries' standard deviation in both subsamples, which suggests that the Portuguese stock market is the most stable stock market in the region.

The measures for skewness and excess kurtosis indicate non-normal distribution of the return in both subsamples. However, the measures for excess kurtosis are lower in the post-crisis sample than in the pre-crisis sample, which is somewhat contradictory to the reported standard deviation. Nevertheless, the more extreme minimum and maximum values of the pre-crisis sample indicate that the most extreme movements in the return actually occurred in the pre-crisis sample. Consequently, the result suggests that the pre-crisis sample is less volatile on average but also that the most extreme movements occur in this period.

The reported Ljung-Box Q statistics for the pre-crisis period suggest significant serial correlation in both the return and squared return for all return series. Again, this result indicates non-randomness and the presence of ARCH effects in the return and heteroskedasticity and the occurrence of GARCH effects in the squared returns. The Ljung-Box Q statistics for the post-crisis period are, however, insignificant at 40 lags for all but the Spanish return series. This implies that all return series, except for the Spanish, follow a random-walk process in the post-crisis period. Yet, the reported Ljung-Box Q statistics for the squared returns in the post-crisis period are significant, which implies serial correlation and the presence of heteroskedasticity.

Table 2: Summary statistics for subsample return series

	Greece	Italy	Portugal	Spain	Greece	Italy	Portugal	Spain
Observations	2270	2270	2270	2270	931	931	931	931
Mean	-0.0046187	-0.0092399	-0.0017427	0.0224667	-0.173696	-0.0210976	-0.0150256	-0.0155482
Min	-9.948921	-8.627663	-10.77514	-9.856358	-9.242676	-6.633347	-5.387144	-7.091632
Max	10.70827	10.9855	9.701799	10.22537	15.95793	10.42965	11.71885	14.52243
Standard deviation	1.592341	1.406938	1.119966	1.522821	2.698657	1.70421	1.337426	1.780385
Skewness	-0.2007661**	-0.0145465	-0.2350531**	0.013378	0.3692461**	-0.0163424	0.4126095**	0.4798154**
Excess Kurtosis	8.486306**	10.50246**	13.64347**	8.490334**	5.029885**	5.61005**	9.85893**	8.630884**
LB(40)	110.2039**	219.7169**	142.1255**	159.2847**	41.0371	45.6175	51.9841	56.994*
LB^2(40)	2465.3315**	3492.5746**	1982.5861**	3261.9792**	159.8658**	330.0421**	118.0582**	144.0986**

Note: The left-hand side shows summary statistics for daily return data for the pre-crisis sample and the right-hand side shows summary statistics for daily return data for the post-crisis sample. Skewness and excess kurtosis test for normal distribution. LB (Ljung-Box statistic) tests for serial correlation in the return and LB^2 tests for serial correlation in the squared return. The number of lags is specified in the parenthesis. The asterisks indicate the statistical significance at 1% (**) and 5% (*) level.

The pairwise unconditional correlations among the four stock markets are given in Table 3. The Greek stock market exhibits the weakest correlation with the other markets in the region. The correlation coefficient is around 0.45 to each of the other stock markets in the full sample period. It is also clearly observable that the correlations between the Greek market and the other markets in the region have dropped since the outbreak of the European debt crisis. In comparison with the Greek stock market, the Portuguese stock market is much more correlated with the Italian and Spanish stock market, with a correlation coefficient of 0.70 and 0.71, respectively, in the full sample period. Also, contrary to the Greek market, the correlation between these markets has increased in the post-crisis period. The strongest correlation in the region appears to be the one between the Italian and Spanish market, with a correlation coefficient of 0.87 in the full sample period. This correlation has also increased since the outbreak of the crisis.

Table 3: Unconditional correlations

Full sample period				
	Greece	Italy	Portugal	Spain
Greece	1.0000			
Italy	0.4465	1.0000		
Portugal	0.4452	0.6992	1.0000	
Spain	0.4484	0.8695	0.7108	1.0000
Pre-crisis period				
	Greece	Italy	Portugal	Spain
Greece	1.0000			
Italy	0.5284	1.0000		
Portugal	0.5030	0.6567	1.0000	
Spain	0.5258	0.8611	0.6784	1.0000
Post-crisis period				
	Greece	Italy	Portugal	Spain
Greece	1.0000			
Italy	0.3597	1.0000		
Portugal	0.3879	0.7696	1.0000	
Spain	0.3683	0.8848	0.7673	1.0000

Note: Unconditional correlation among stock market returns for the full sample period, for the pre-crisis period, and for the post crisis period.

The Augmented Dickey-Fuller (ADF) test is used to examine whether the index series contain a unit root or not. Most researchers agree that the financial times series are integrated and thus share a unit root, which in turn is an indication of cointegration. The level of integration in each index series must, however, be identified before they can be tested for cointegration. The result of the ADF test is presented in Table 4. The ADF tau-statistics for the log-levels fail to reject the null hypothesis of non-stationarity. However, the first difference of the log-level for each index series is significant and

consequently rejects the null hypothesis. The result suggests that the four index series are integrated of order one.

Table 4: Augmented Dickey-Fuller

	Greece	Italy	Portugal	Spain
Log-level	-0.134	-1.797	-1.491	-1.570
First difference	-55.558**	-56.850 **	-53.356**	-56.444**

Note: The presented numbers are ADF tau-statistic which testing the null hypothesis of non-stationarity with a one tail test of significance. The chosen ADF-model includes trend and intercept. The Schwarz Bayesian information criterion is used to select the number of lags. The asterisks indicate the statistical significance at 1% (**) and 5% (*) level.

The primarily results indicate that the index series have a unit root and are integrated of order one. Consequently, the Johansen test of cointegration is an appropriate method for testing whether the four stock markets are cointegrated. Furthermore, the preliminary results also imply that each return series exhibits ARCH and GARCH effects. This suggests that the DCC-MGARCH model fits the purpose for the investigation of the short-run spillovers.

5. Empirical results

5.1 Long-run cointegration

Since the four index series are found to be integrated of order one, a Johansen test of cointegration is performed. The lag length selection is based on Schwarz Bayesian information criterion. Due to the sensitivity of the test to the specification of trend and intercept in the VAR-model, all five combinations[8] of the test are applied. The result presented in Table 5 is from the restricted trend specification[9], the specification which yielded most significant values.

The trace statistics from Johansen multivariate cointegration test reject the null hypothesis of no cointegrating relationship (63.7489>62.99) but fail to reject the null hypothesis of at most one cointegrating relationship (25.475<42.44). Consequently, the null hypothesis of one cointegrating relationship is accepted. In other words, the result of Johansen multivariate relationship shows evidence of one long-run cointegrating relationship.

Table 5: Johansen multivariate cointegration test

Cointegrating rank	Eigen value	Trace	Critical value
R=0	0.01182	63.7489	62.99
R≤1	0.00432	25.475	42.44
R≤2	0.00296	11.5463	25.32
R≤3	0.00062	1.9963	12.25

Note: The presented numbers are trace-statistic which testing the null hypothesis of R cointegrating relationships. The chosen specification includes a restricted trend. The Schwarz Bayesian information criterion is used to select the number of lags. The critical values are at the 95% level.

The results from Johansen bivariate cointegration test for all pairwise combinations are displayed in Table 6. All tests involving either the Greek or Italian stock market fail to reject the null hypothesis of no cointegration. This means that there is no evidence of any long-run relationship between the stock markets in Greece and Italy, Greece and Portugal, Greece and Spain, Italy and Portugal, and

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[8] These are unrestricted trend, restricted trend, unrestricted constant, restricted constant, and no trend.
[9] The trend is assumed to be linear but not quadratic, which allows the equation to be trend stationary.

Italy and Spain. However, the trace statistics from Johansen bivariate cointegration test between the Portuguese and Spanish stock exceeds the test statics for no cointegration (34.8326>25.32), which means that the null hypothesis of no cointegration is rejected. The result of the test clearly shows evidence of long-run cointegration between the stock markets in Portugal and Spain.

Table 6: Johansen bivariate cointegration test

Cointegrating rank	Eigen value	Trace	Critical value
Greece-Italy			
R=0	0.00436	15.3844	25.32
R≤1	0.0004	1.3011	12.25
Greece-Portugal			
R=0	0.00273	10.2221	25.32
R≤1	0.00044	1.4191	12.25
Greece-Spain			
R=0	0.00553	19.4707	25.32
R≤1	0.0005	1.6041	12.25
Italy-Portugal			
R=0	0.01182	22.0569	25.32
R≤1	0.00432	2.8253	12.25
Italy-Spain			
R=0	0.00274	12.1915	25.32
R≤1	0.00104	3.3611	12.25
Portugal-Spain			
R=0	0.00994	34.8326	25.32
R≤1	0.00082	2.6483	12.25

Note: The presented numbers are trace-statistic which testing the null hypothesis of R cointegrating relationships. The chosen specification includes a restricted trend. The Schwarz Bayesian information criterion is used to select the number of lags. The critical values are at the 95% level.

The evidence of only one cointegrating relationship among the four stock markets in the Eurozone´s southern periphery is not surprising. Cointegration between two or more markets assumes an analogous stochastic drift rate over long time. The efficient market theory suggests, however, that financial time series are a random walk process which, in turn, precludes cointegration. The index series may react analogously to global shocks in the short-run but it is also reasonable to believe that they will develop differently in the long-run due to country-specific conditions and shocks. The evidences of no cointegration between the stock markets in Italy and Spain support those provided by Richards (1995), who found no cointegration between these two markets using monthly data from 1974 to 1990. Yet, the results from Johansen bivariate cointegration test reveal a cointegrating relationship between the Portuguese and Spanish stock markets. This means that these two markets must react analogously to country-specific shocks as well, which indicates that a country-specific shock in one market is followed by an offsetting shock in the other market. By considering the relative size of these two, it is most likely that the Portuguese market offsets the shocks introduced in the Spanish market. The result implies a very high degree of financial integration between the two countries, which might be due to their geographic proximity.

   The result shows that there is one specific long-term relationship among the four stock markets that have to be modeled with a VEC model. However, since the DCC-MGARCH model will be applied in a multivariate framework and since the majority of the return series show no evidence of cointegration, any long-run relationship will not be taken into account when the short-run mean spillovers are estimated.

5.2 Short-run dynamic linkages

Since the cointegration tests showed that any but the Portuguese and Spanish stock markets were cointegrated, any mean spillovers will be consider as short-run in nature. A VAR framework will therefore be used. Moreover, as seen in section 5, all return series showed tendency of ARCH and GARCH effects. Seemingly, a DCC-MGARCH model is appropriate to capture the observed characteristics of the data. Again, the Schwarz Bayesian information criterion is used to determine the optimal lag length in the mean equation. The result presented in Table 7 is from a VAR(1)-DCC-MGARCH(1,1) specification for the full sample period.

Own-volatility spillovers are significant in all markets supporting the observed tendency of ARCH-effects. The magnitude ranges from 0.0616 in Italy to 0.0725 in Portugal. Own volatility persistence is also significant in all markets, verifying the observed tendency of GARCH effects. The persistence of stock market volatility ranges from 0.9147 in Portugal to 0.9317 in Italy. The result implies that past volatility shocks have the lowest effect on future volatility in the Italian stock market but also that this market derives the highest volatility persistence from within its own market. Vice versa is true for the Portuguese market, while the Greek and Spanish markets are in between.

The mean equations indicate significant unidirectional return spillovers from the Italian to the Spanish stock market as well as reciprocal return spillovers between the Portuguese and Spanish stock markets. A 1% increase in the Italian and Portuguese markets will cause the Spanish market to decrease by 0.0762% and 0.0603% the following day, respectively. A 1% increase in the Spanish market will, on the other hand, cause the Portuguese market to increase by 0.0739% the following day. The future mean return of one day in Spain and Italy will also be influenced by its own present return shocks; Spain with positive 0.0753% and Italy with negative 0.0642%.

All pairwise dynamic conditional correlation coefficients are significant, thus indicating volatility correlation between all markets in the Eurozone´s southern periphery. The strongest volatility correlation is between the Italian and Spanish stock market with a correlation coefficient of 0.8672. The result also shows a close to equal magnitude in volatility correlation between the Portuguese and Spanish markets, with a correlation coefficient of 0.6659, and the Portuguese and Italian market, with a correlation coefficient of 0.6544. Moreover, it is clearly evident that the weakest pairwise volatility correlation in the region involves the Greek stock market. Particularly, the volatility correlation between the Greek and the Portuguese markets are weak, with a correlation coefficient of 0.4143.

	Greece (i=1)	Italy (i=2)	Portugal (i=3)	Spain (i=4)
Own effects				
α_o	0.0170406**	0.0142621**	0.016577**	0.0200817**
α_1	0.0705735**	0.0615632**	0.0725337**	0.0629105**
β_1	0.9275155**	0.9316914**	0.9148678**	0.9292065**
Mean spillovers				
γ_{i0}	0.0864813**	0.0735973**	0.0725946**	0.1044547
γ_{i1}	0.0161582	0.0224291	0.0058351	0.0181068
γ_{i2}	0.0726685	-0.0641987*	-0.046624	-0.0761895*
γ_{i3}	-0.038919	-0.0181763	0.0131544	-0.0602529*
γ_{i4}	0.0364917	0.031764	0.0738395**	0.0752534*
Conditional correlation				
ρ_{12}	0.4689874**			
ρ_{13}	0.414254**			
ρ_{14}	0.4758272**			
ρ_{23}	0.6544357**			
ρ_{24}	0.867212**			
ρ_{34}	0.6659057**			

Note: Estimated coefficients for the full sample period. α is the ARCH coefficient, β is the GARCH coefficient, γ is the mean coefficent, and ρ is the conditional correlation coefficient. The Schwarz Bayesian information criterion is used to select the number of lags. The asterisks indicate the statistical significance at 1% (**) and 5% (*) level.

Table 8 presents the empirical results for the pre- and post-crisis period. Again, a VAR(1)-DCC-MGARCH(1,1) specification for each subsample period has been used to capture the observed characteristic of the data.

The volatility induced from within the domestic markets has, on average, increased since the outbreak of the European debt crisis. The magnitude of own volatility spillovers has increased in all markets but the Italian in the post-crisis period. The magnitude ranges from 0.0643 in Spain to 0.0744 in Greece in the pre-crisis period and from 0.0569 in Italy to 0.0869 in Portugal in the post-crisis period. The persistence of own volatility spillovers has, however, decreased in all markets since the start of the crisis. The persistence of stock market volatility ranges from 0.9126 in Portugal to 0.9254 in Spain in the pre-crisis period and from 0.8431 in Greece to 0.9125 in Italy in the post-crisis period.

The mean spillovers in the pre-crisis period have the same direction as in the full sample period. Again, there are a unidirectional spillovers from the Italian to the Spanish stock market and reciprocal spillovers between the Portuguese and Spanish market. However, the outbreak of the European debt crisis has affected the mean spillovers in the region. It is clearly observable that the strength of the spillovers from the Spanish to the Portuguese stock market has increased since the start of the crisis. A 1% increase in the Spanish market will cause the Portuguese market to increase by 0.1367% the following day in the post-crisis period. Corresponding figure for the pre-sample period is 0.0638%. Moreover, the spillovers from the Italian and Portuguese markets to the Spanish market are not significant in the post-crisis period. However, future mean return of one day in Spain is significantly influenced by the present return in Greece in the post-crisis period. A 1% increase in the Greek market will cause the Spanish market to increase by 0.0414%

The volatility correlation is greater between the markets in Italy and Portugal, Italy and Spain, and Portugal and Spain in the post-crisis period. The estimated correlation coefficients for these markets are 0.7125, 0.8879, and 0.06979, respectively, in the post-crisis period. Corresponding figures in the pre-crisis period are 0.5933, 0.8559, and 0.6199. On the contrary, volatility correlation involving the Greek market has become weaker in the post-crisis period. The estimated correlation coefficients between the markets in Greece and Italy, Greece and Portugal, and Greece and Spain are 0.2835,

0.2989, and 0.3038, respectively, in the post-crisis period. Corresponding figures in the pre-crisis period are 0.5098, 0.4225, and 0.5208.

Table 8: DCC-MGARCH estimates for subsamples

	Greece (i=1)	Italy (i=2)	Portugal (i=3)	Spain (i=4)	Greece (i=1)	Italy (i=2)	Portugal (i=3)	Spain (i=4)
Own effects								
α_o	0.0271012**	0.0153682**	0.015291**	0.0198975**	0.4846154*	0.0684024**	0.0989459**	0.0979598**
α_1	0.0744394**	0.0671626**	0.0729854**	0.0643185**	0.0867856**	0.0569317**	0.0868895**	0.0675964**
β_1	0.9152898**	0.9229205**	0.9126296**	0.9254141**	0.8431866**	0.9125265**	0.8436342**	0.8945746**
Mean spillovers								
γ_{i0}	0.0939475**	0.0768994**	0.0766356**	0.1133595**	-0.0255555	0.0556942	0.0556942	0.0780197
γ_{i1}	0.044505	0.0236685	-0.0147097	-0.006811	-0.0599276	0.0231355	-0.0147097	0.041439*
γ_{i2}	0.0706655	-.0669923	-.0475144	-.1032518*	0.0312868	-.0619378	-.0475144	-.0632742
γ_{i3}	0.0135167	-0.0195969	0.0315509	-.0652534*	-0.0718709	-0.0251842	0.0315509	-.0330643
γ_{i4}	0.0364917	0.0132303	0.0638088*	0.0824602*	0.1819286	0.1367373	0.1367373**	0.1018797
Conditional correlation								
ρ_{12}	0.5098236**				0.2834456**			
ρ_{13}	0.4225108**				0.2989299**			
ρ_{14}	0.5207836**				0.3038118**			
ρ_{23}	0.5932766**				0.7125192**			
ρ_{24}	0.8559178**				0.8778461**			
ρ_{34}	0.6199033**				0.6974931**			

Note: The left-hand side shows estimated coefficients for the pre-crisis sample and the right-hand side shows the estimated coefficients post-crisis sample. α is the ARCH coefficient, β is the GARCH coefficient, γ is the mean coefficent, and ρ is the conditional correlation coefficient. The Schwarz Bayesian information criterion is used to select the number of lags. The asterisks indicate the statistical significance at 1% (**) and 5% (*) level.

The evidences of mean spillovers in the Eurozone´s southern periphery are few and, by comparing the two subsamples, mostly inconsistent. The Italian and Portuguese stock market obviously spillover to the Spanish stock market prior the crisis but not after the outbreak. The Greek market, on the other hand, spills over to the Spanish in post-crisis period but not in the pre-crisis period. The only consistent finding is that the Spanish market is the main source of mean spillover to the Portuguese market. This result supports previous evidence of long-run cointegrating relationship between those two markets and further indicates that the Portuguese stock market is closely tied to the Spanish. This result also supports previous findings, such as those provided by Janakirmanan and Lamba (1998), who found that geographical proximity tends to increase the likelihood of market dependencies. Furthermore, the fact that the Spanish market reacts significantly to return shocks transpired from the other three markets, either in the pre-crisis period or the post-crisis period, is another interesting finding. This result indicates high interregional sensitivity of the Spanish market.

The empirical evidences of volatility correlation indicate that the Italian and the Spanish market are the dominant stock markets in volatility transmission in the region, as the greatest correlation are between markets involving either of these two markets. This result is not very surprising given the relative size of these two market indices and is in line with the results presented by Bartram et al (2007), who revealed that the largest regional indices are the major source of volatility in their particular region.

A fair assumption would have been that the Portuguese market had a higher degree of volatility correlation with the Spanish market due to previous findings of high financial integration between the two markets. However, the result shows that the magnitude of volatility correlation between the Italian and Portuguese and the Spanish and the Portuguese are fairly comparable, suggesting that volatility induced in the Italian and Spanish markets transpire to the Portuguese market with approximately the same magnitude.

It is clearly evident that the weakest pairwise volatility correlations in the region involve the Greek stock market. Particularly, the volatility correlation between the Greek and the Portuguese markets are weak. This result is fairly natural given the geographic distance and their relative market size. Nevertheless, the evidence of significant volatility correlation between the Greek and the other markets in the region supports those presented by Adel and Salma (2012), who found volatility correlation between the Greek stock market and several other stock markets in the Euro area, including the Italian, the Portuguese, and the Spanish stock markets.

Another interesting feature of the results is that volatility correlation has increased since the outbreak of the European debt crisis between all pairwise comparisons except for these involving the Greek market. The further result is well in line with previous literature, such as Koutmos and Booth (1995), Kanas (1998), Chiang et al (2007) , Yilmaz (2010), Boubaker and Jaghoubi (2011) and Zhou et al (2012), who have showed that that volatility linkages tend to increase in times of financial turmoil. The latter result is, however, somewhat unexpected. The fact that the Greek market is less correlated with the other markets in the region in the post-crisis period is an obvious indication of market isolation, which possibly could be explained by the fact that foreign ownership of Greek stocks has dramatically decreased since the start of the crisis. The result both supports and opposes those presented by Adel and Salma (2012), who showed that the market dependencies, after the occurrence of the crisis, have become weaker between the Greek and Spanish markets but stronger between the Greek and Italian markets and the Greek and Portuguese markets.

The results of the correlation coefficients are supported by the conditional variance processes illustrated in Figure 3. The stock market in Greece seems to move more independent compare to the other stock markets in the region, particularly from the start of the European debt crisis. It is also observable that the Italian and Spanish stock markets are those markets where the volatility processes closely together; periods of low and high volatility clearly coincide in these two markets.
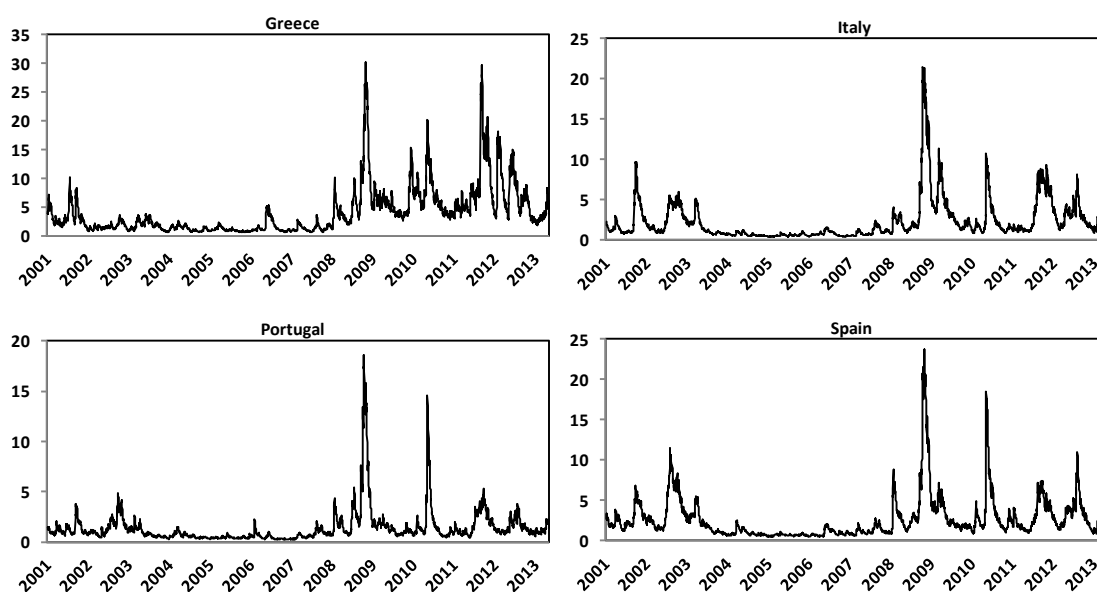

Figure 3: Conditional variance

The empirical results presented in this section provide evidence of significant short-run dynamic linkages among the markets in the Eurozone´s southern periphery. These results are important for

investors and policy-makers, both inside and outside the region. For investors, an understanding of the short-run dynamic linkages among the four markets is important when constructing a diversified portfolio. The fact that the Greek market is less dependent on the development in the other markets in the region may positively affect the scope of diversification. On the other hand, a reason to the higher independency might be foreign investors' reluctance to invest on the Greek market, which is due to high country-specific risk. For policy-makers, an understanding of the short-run dynamic linkages is imperative when designing regulatory mechanisms, especially since the outbreak of the European debt crisis has strongly impacted the strength of the correlation in the region. Overall, correlation does exist among all markets in the region, especially between markets including either the Italian or the Spanish, which highlights the importance of sound portfolio management and regulatory policies.

6. Robustness tests

The robustness of the chosen DCC-MGARCH models is examined by diagnostic checking the standardized residuals. The standardized residuals are tested for non-normality and serial correlation in the level and squared term. The results of the robustness test for the full sample period model, the pre-crisis model, and the post-crisis period are presented in Table 9.

It is clearly observable that the models have problems to correct for non-normality. The tests of skewness and excess kurtosis of the standardized residuals are significant in most cases. Moreover, the tests for serial correlation in level and squared residuals show some existence of serial correlation. In particular the residuals of the Spanish return series indicates serial correlation in the full sample period and the pre-crisis period. The squared standardized residuals of the Italian return series is significant in the full sample period and the pre-crisis period as well. Also, the level residual of the Portuguese return series is significant in the pre-crisis period.

Table 9: Residual diagnostics

	Greece	Italy	Portugal	Spain
Full sample period				
Skewness	0.04878	-0.362837**	-0.1525149**	-0.229227**
Excess Kurtosis	4.408682	4.338636**	5.244639**	4.837791**
LB(40)	33.3506	49.8336	47.7893	66.7496**
LB^2(40)	48.9476	111.3955**	35.5166	85.6605**
Pre-crisis period				
Skewness	-0.1130204*	-0.4273427*	-0.1594163**	-0.3789545**
Excess Kurtosis	4.412487**	4.247847**	5.883006**	4.698304**
LB(40)	43.0239	55.1652	67.6423**	74.4032**
LB^2(40)	55.1785	84.1551**	38.9285	76.9489**
Post-crisis period				
Skewness	0.4182544*	-0.1559989*	-0.064444	0.1661557**
Excess Kurtosis	4.583639**	4.24596**	4.27251**	5.073926**
LB(40)	34.3285	30.8685	27.4615	40.8311
LB^2(40)	48.3564	50.4692	34.4869	46.8954

Note: Summary statistics for standardized residuals for the full sample period, the pre-crisis period, and the post-crisis period. Skewness and excess kurtosis test for normal distribution. LB (Ljung-Box statistic) tests for serial correlation in the level residuals and LB^2 tests for serial correlation in the squared residuals. The number of lags is specified in the parenthesis. The asterisks indicate the statistical significance at 1% (**), and 5% (*) level.

The problems with non-normality in the return series are similar to those experienced by Kanas and Kouretas and Zarangas (2001) and Johansson and Ljungwall (2008). These authors conclude, however, that their models are well-specified despite some existence of non-normality in the standardized residuals. The problems with serial correlation in the level and squared standardized residuals are more serious and indicate specification errors. Different models have, however, been specified without improving the robustness. Overall, the residual diagnostics reveals some specification problems, particularly in the models used for the full sample period and the pre-crisis period. These problems might cause the estimated coefficients to be biased.

7. Conclusion

Recent events in the Eurozone´s southern periphery have directed much interest to the region. Yet, only a limited number of studies have targeted the market interdependencies in these counties. This thesis has examined the interdependencies among the stock markets in the Eurozone´s southern periphery, before and after the outbreak of the European debt crisis. By applying the Johansen test of cointegration and the DCC-MGARCH model, both the long-run and short-run interdependencies have been examined.

The Johansen test of cointegration showed evidence of long-run relationship between the stock markets in Portugal and Spain. This result implies a very high degree of financial integration between the two countries, which might be due to their geographic proximity. The Johansen test of cointegration gave, however, no indication of long-run relationships between the other markets in the region. This result is in accordance with the efficient market theory, which suggests that financial time series are a random walk process that precludes cointegration.

The result from the DCC-MGARCH model showed evidence of short-run dynamic linkages among the stock markets in the Eurozone´s southern periphery, particularly in the form of volatility correlation. The volatility correlation in the region is found to be strongest between the Italian and the Spanish stock markets. On the contrary, the Greek stock market is found to be the market in the region which exhibits lowest volatility correlation to the other markets in the region. Furthermore, the stock market most sensitive to mean spillovers in the region is found to be the Spanish. The fact that short-run dynamics linkages do exist among all markets in the region is imperative for investors and policy makers and highlights the importance of sound portfolio management and regulatory policies.

The result also indicates that the outbreak of the European debt crisis has affected the volatility correlations in the region. The main finding is that the volatility correlation has increased since the outbreak of the European debt crisis between all pairwise comparisons except for these involving the Greek market. The further result is well in line with previous literature, which indicates that volatility correlation tend to increase in times of financial turmoil. The latter result is an obvious indication of market isolation, which possibly could be explained by the fact that foreign ownership of Greek stocks has dramatically decreased since the start of the crisis.

This thesis contributes to the literature on stock market interdependencies by assessing the long-run cointegration relationship as well as the short-run dynamics in the Eurozone´s southern periphery,

before and after the outbreak of the European debt crisis. Despite some model specification problems, the results obtained can provide a framework for policy makers, regulators and portfolio managers to curb potential contagious effects within and outside the region.

The daily data used in this this may be biased of non-synchronized trading and the day of the week effect. Consequently, it would be of interest for further research to examine whether the uses of weekly or monthly data would yield another result. Moreover, this investigation has been based on the assumption that positive and negative innovations in one market transpire to other markets with the same magnitude. Therefore, another area of interest for further research would be to examine whether the positive and negative innovations in one market asymmetrically impact the other markets.

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