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A dynamic conditional correlation analysis of European stock markets from the perspective of the Greek sovereign debt crisis

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Abstract

By using the asymmetric dynamic conditional correlation model developed by Cappiello et al. (2006), we examine how the time-varying correlations between Greece and other six European countries (Germany, France, UK, Ireland, Italy, and Spain) evolved from January 2007 to March 2011. The main contribution of the study is investigating whether the financial turmoil that originated from one nation's government debt market can exert contagion effects on equity markets in other countries of the region. We show that the dynamic correlations exhibited swings over time with several peaks, particularly in September 2008 and May 2010 and, interestingly, that the correlations indicated significant declines (rather than increases) during the sovereign debt crisis. The results imply that diversification opportunities between Greece and the other six European nations may have been created since the debt crisis intensified.

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1. Introduction

Using the asymmetric Dynamic Conditional Correlation (DCC) model developed by Cappiello et al. (2006), this paper investigates the movement of correlations of stock market indices between Greece and other six European countries. After the inception of the sovereign debt crisis in Greece in late 2009, policy makers in European nations and international investors have begun to have imminent fears over potential risks of financial contagion across the Eurozone. In fact, according to Eurostat, as the yield of the Greek 10-year government bond rose sharply from around 4.5% in October 2010 to over 9.5% in April 2011, that of Portugal also increased from around 4% to over 6% during the period. Moreover, Spain's 10-year government bond yield followed a sharp upward trend after a three-month time lag, thereby implying the possibility of spillover effects from Greece's sovereign market to that of Portugal and Spain, both of which have in common with Greece high percentages of government debt over GDP and net foreign assets over GDP. Such co-movement was also observed in the European stock markets, particularly in early May 2010 (specifically from May 4 to May 7), when the stock markets of Britain, France, Spain, and Italy faced visible declines, apparently coinciding with drops in the Greek stock index. Thus, this leads to an interesting research question of whether Greece, which holds only 2.7% of Eurozone's total GDP but is seen as the main source of the recent European sovereign debt crisis, had really exerted "contagion effects" on other major European stock markets during the period of its burgeoning financial turmoil.

Despite differences in the definition of financial contagion among economists, a significant number of recent studies have regarded notable increases in the correlations of asset prices across countries during the financial turmoil as evidence of contagion effects. Based on this understanding, a strand of literatures has been cultivated with the DCC framework first developed by Engle (2002) and its modified versions of models. Engle's (2002) DCC model comprises two steps—fitting each of the time series to univariate GARCH models and then deriving the dynamic conditional correlation estimate. This is primarily designed to ensure computational advantages over the conventional multivariate GARCH models in terms of capturing the time-dependent nature of the correlation of stock returns across markets. Its modification by Cappiello et al. (2006), named the asymmetric DCC model, aimed to incorporate the possibility of occasionally observed events in which the conditional correlation of stock returns is more significantly influenced by negative shocks than positive shocks.

The DCC and asymmetric DCC models have spurred a proliferation of studies on the dynamics of the stock market conditional correlation, particularly in the context of Asian markets during the Asian financial (1997–1998) and global financial crises (2007–2009) triggered by sub-prime loan issues in the US. Major examples in this regard include the following studies. Yang (2005), applying the DCC model to daily stock index data from 1990 to 2003, investigated the conditional correlations between Japan and four Asian countries (Hong Kong, Taiwan, South Korea, and Singapore) and found increases in the correlations, particularly when high volatilities were observed during the Asian financial crisis. Kuper and Lestano (2007) also used Engle's (2002) DCC framework to analyze dynamic correlations of not only daily stock returns but also daily exchange rates and interest rates between Indonesia and Thailand. Their findings reveal that the correlations first declined at the inception of the Asian financial crisis before abrupt jumps, thereby indicating that contagion across countries may take some time. Cheung et al. (2008), studying weekly stock index data in the US, East Asia, and Pacific region using the DCC model, found significant contagion effects within the East Asia and Pacific region during the global financial crisis period; however, they identify no evidence of contagion between the US and each country in the region. Yiu et al. (2010), using the asymmetric DCC model for weekly stock index data, examined the dynamic correlations between the US and eleven Asian nations and suggested the existence of contagion from the US market during the global financial crisis period.

In contrast, a relatively small number of studies touch upon contexts of time-varying correlations among European stock markets and tend to focus on analyzing the impacts of the introduction of the euro (rather than the financial crisis) on the dynamics of correlations (e.g., Bartnum et al., 2007; Kenourgios et al., 2009; Savva et al., 2009). To the best of our knowledge, this study is the first to evaluate the potential impacts of the recent European sovereign debt crisis on the dynamics of stock market correlations between Greece, where the crisis originated, and the abovementioned six European nations. From this viewpoint, we believe that the main contributions of our analysis are twofold. First, we empirically address an interesting question regarding whether financial turmoil that originates from solvency issues of a particular nation and spreads to its bond markets can trigger significant contagion effects across borders in regional equity markets. Second, our empirical study indicates the extent to which European stock markets, which are considered to have attained more solid economic integration than Asian markets, may be influenced by spillover effects due to the sovereign debt crisis.

The remainder of the paper is organized in the following manner. Section 2 describes the econometric methodology used in our study. Section 3 provides a detailed description of our dataset. Section 4 summarizes our empirical results. In the final analysis, Section 5 presents some concluding remarks.

2. Methodology

Similar to Yiu et al. (2010), we take the following three steps in our analytical framework. First, we estimate the conditional variances of each of the stock returns using univariate

GARCH models. Our approach differs from that of Yiu et al. (2010) in that instead of simply using GARCH (1,1) models, we select the best of AR(*k*)-EGARCH(*p*,*q*) models. Let us denote the stock returns by r_t. Then, the conditional mean and variance of returns in the AR(*k*)-EGARCH(*p*,*q*) framework are represented as

$$r_t = \varphi_0 + \sum_{i=1}^{k} \varphi_i r_{t-i} + \varepsilon_t \quad \text{and} \tag{1}$$

$$\log(d_t) = \omega + \sum_{i=1}^{p} (\alpha_i \left| \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right| + \gamma_i \frac{\varepsilon_{t-i}}{\sigma_{t-i}}) + \sum_{i=1}^{q} \beta_i \log(d_{t-i}) \,, \tag{2}$$

where *k* (=1, 2, …, 10), *p* (=1, 2), and *q* (=1, 2) are selected by the Schwarz Bayesian information criterion (SBIC).

Second, we derive the time-varying conditional correlations with the asymmetric DCC model developed by Cappiello et al. (2006). Let us denote the standardized regression obtained above as

$$\overline{\varepsilon_t} = \varepsilon_t \big/ \sqrt{d_t} \,. \tag{3}$$

The negative standardized residuals for capturing asymmetric impacts are defined by

$$\overline{\eta_t} = \overline{\varepsilon_t} \text{ if } \overline{\varepsilon}_t < 0 \text{ and } \overline{\eta_t} = 0 \text{ otherwise.} \tag{4}$$

Then, with the conditional correlation matrix denoted by P_t and the unconditional correlation matrix between residuals denoted by $\overline{P}$, the asymmetric DCC (1,1) model is given by

$$P_t = Q_t^{*-1} Q_t Q_t^{*-1} \tag{5}$$

$$Q_t = (1 - a_1 - b_1)\overline{P} - g_1 \overline{N} + a_1 \overline{\varepsilon_{t-1}}\,\overline{\varepsilon_{t-1}^{'}} + g_1 \eta_{t-1} \eta'_{t-1} + b_1 Q_{t-1} \tag{6}$$

where Q_t is the conditional covariance matrix between the standardized residuals and Q_t^* is a diagonal matrix with the squared i-th diagonal element of Q_t on its i-th diagonal position.

Third, AR (1) models are applied to model the conditional correlations derived from the second step. Specifically, the dummy variable signifying the sovereign debt crisis period (i.e., from November 5, 2009, to March 31, 2011) is included in order to test whether the debt crisis significantly altered the dynamics of the estimated conditional correlations between Greece and the abovementioned six countries; that is,

$$\hat{DCC}_t = \delta_0 + \delta_1 \hat{DCC}_{t-1} + \xi_1 Crisis_t + v_t \, . \tag{7}$$

3. The Data

Our dataset comprises daily returns of stock market indices (1046 observations in total) for the period from January 1, 2007 to March 31, 2011 for seven European countries. These indices are FTSE/ATHEX 20 (Greece), ISEQ-OVERALL PRICE (Ireland), FTSE MIB (Italy), IBEX 35 (Spain), DAX (Germany), CAC 40 (France), and FTSE 100 (UK). All the data are extracted from the Yahoo Finance website[1]. Daily stock returns are defined as the difference of the logarithm of the index, multiplied by 100 to express as percentages. In terms of unavailable data points due to holidays in each country, the stock prices were assumed to be the same as the prices of the previous day, similar to Savva et al. (2009). All the indices are denominated in euro, except for the UK's FTSE 100, denominated in British pounds. The reasons why we use daily data are twofold. First, the use of daily data will allow us to avoid the potential issue of overlooking temporary spillover effects that might arise by using lower frequency data. Second, the daily dataset can provide a sufficient number of samples for our study on the recent phenomena of the European sovereign debt crisis.

Table 1 presents a summary of descriptive statistics of our data. "Pre-crisis period" and "post-crisis period" are defined such that November 5, 2009, the date when the Greek government disclosed its fiscal deficit at 12.7% of GDP (approximately twice of what had been announced previously), represents the beginning of the sovereign debt crisis. This is because investors' perceptions regarding the nation's solvency might have been altered since then. Over the entire sample period, all the countries except Germany experienced a negative return in mean; this is not surprising as our sample also contains a period of the global financial crisis beginning in autumn 2007. It must be noted that the mean of the daily stock returns relatively increased in all other six countries after the sovereign debt crisis, while in Greece the mean declined from -0.08% during the pre-crisis period to -0.2% in the post-crisis period. Changes in the standard deviations also exhibited a similar pattern. The level of kurtosis for the stock returns decreased during the debt crisis, except for Spain. Jacque-Bera tests reject normality for all the seven countries concerned. It is also confirmed that on the basis of Augmented Dickey-Fuller (ADF), tests we do not identify unit root processes for

[1] We also considered the possibility of including Portugal, one of the "PIIGS" countries, in our analysis. However, the data on Portugal's PSI 20 index extracted from Yahoo Finance include a series of missing data points from August 18 to December 23, 2009. Hence, we chose not to use the PSI 20 data in order to ensure compatibility with stock indices data for other countries.

level data at the 1% significance level.

4. Empirical Results and Discussion

AR-EGARCH specification

Our approach is the first to fit the best of univariate AR(*k*)-EGARCH(*p*,*q*) models to each series of the stock returns for the seven European countries. This is a main difference of this study from the approaches used in Yang (2005) and Yiu et al. (2010), both of which simply apply GARCH(1,1) models.

As indicated in Table 2, we chose AR(1)-EGARCH(1,1) for all the seven countries except Greece, for which AR(2)-EGARCH(1,1) is found to be appropriate. The variance equations of the models exhibit good fit to the data with all parameters including the GARCH and asymmetric terms found to be significant at the 1% significance level. Moreover, the p-values of the Ljung-Box statistics, $Q(20)$ and $Q^2(20)$, are much larger than 0.01 for all seven nations, thereby suggesting acceptance of the null hypothesis of no autocorrelation up to order 20 for standardized residuals and standard residuals squared. However, in contrast, parameters in the mean equations are not significant even at the 10% significance level, except for those in the case of Greece. As our analysis focuses on the dynamics of correlations of the stock returns, the well-fitted variance equations motivate us to conclude that our AR-EGARCH models fit the dataset reasonably well.

Estimation of asymmetric DCC models

Our second step is to derive the estimates of the asymmetric DCC models developed by Cappiello et al. (2006). Table 3 presents the DCC estimates. Both the estimates on the parameter of standardized residuals (a_i) and the parameter of innovations in the dynamics of the conditional correlation matrix (b_i) are statistically significant for all the nations. On the other hand, the estimates on the parameter of the standardized negative residuals (g_i) are not significant even at the 10% significance level for all seven countries. That is, the conditional correlation of stock index returns is not necessarily influenced more significantly by negative innovations than by positive innovations to return. This insignificance of the parameter g_i is quite consistent with the empirical results of Yiu et al. (2010), where the dynamic correlation between the US and eleven Asian nations is examined for sample periods from February 1993 to March 2009 (including the global financial crisis period). We also compare the log-likelihood values between the asymmetric DCC model and Engle's (2002) DCC model and confirm that the former model slightly outperforms the latter (although the log-likelihood values are not reported in the table).

Fig 1 describes the estimates on time-varying conditional correlations between Greece and each of the other six countries. From the graphs, we highlight the following four key findings. First, correlations of the Greek stock indices exhibited more substantial fluctuations with Ireland than with the main countries in the Eurozone countries (Germany, France, Spain, and Italy). Such fluctuations in the case of Ireland may stem from the relatively low estimate (0.479) on the parameter of the innovations in the dynamics of the conditional correlation matrix (b_1), as indicated in Table 3. Second, prior to the sovereign debt crisis that occurred in late 2009, the Greek stock market's correlations with the other six nations had moved up and down, with the highest peak in the fourth quarter of 2008. During the peak period, the risk of a systemic meltdown in global financial markets emerged most fiercely in September 2008 when Lehman Brothers filed for bankruptcy. The evidence of the contagion effects demonstrated in Fig 1 at this period is in line with the analysis of Liquane et al. (2010), which identified sharp increases in dynamic conditional correlations between the US stock market and the stock markets of several developed nations and emerging countries. Third, after the inception of the sovereign debt crisis, notable peaks of the correlations were found in the second quarter of 2010, most clearly in terms of the correlation between Greece and Spain. The peaks coincided with falls of prices in major European stock markets in early May when street protests in Athens were reported and doubt was cast on Greece's ability to manage the levels of its government debt. However, Fig 1 indicates that the contagion effects reflected in increases in the dynamic correlations were transient and smaller than those triggered by the global financial crisis after 2007. Fourth, and most importantly, after May 2010 the dynamic correlations began exhibiting downward trends. In particular, the correlations with Germany, France, and the UK declined to lower levels than those in the beginning of 2007, thereby suggesting that diversification opportunities between Greece and these countries in fact increased through the sovereign debt crisis.

AR model for the estimated dynamic conditional correlation

Our last step is to apply AR (1) models with a dummy variable representing the European sovereign crisis period to the evolution of the estimated dynamic conditional correlations. Table 4 reports the estimations of the regression models. The constant terms (δ_0) are all positive and significant at the 5% significance level. The correlation between Greece and Ireland is highest with the estimated constant term of 0.204 over the sample period. The coefficients of AR terms (δ_1) are also significant for all cases at the 1% significance level with values of less than unity, thereby indicating the stationary property. A relatively high R^2 ensures the adequacy of the AR (1) models.

The coefficients of crisis dummies (ξ_1) are all found to be negative and statistically significant at the 10% significance level. This may suggest that contagion effects from the Greek stock index to other countries' indices are not identified during the debt sovereign crisis period. Negative coefficients also imply that the six countries (Ireland, Italy, Spain, Germany, France, and the UK) may be reasonably suitable for diversification when investors consider investment in the Greek stock index.

5. Conclusion

In this article, we extend the strands of our research on the dynamic conditional correlation analysis of international stock markets by evaluating how the correlations between Greece and other six major European countries evolved from January 2007 to March 2011. A particular focus was placed on analyzing the impacts of the Greek sovereign debt crisis on the dynamics of stock market correlations. The correlations were found to undergo swings over time with remarkable peaks in the fourth quarter of 2008, prior to the sovereign debt crisis, and in the second quarter of 2010, during the crisis. It was also indicated that the correlations generally exhibited downward trends after May 2010. In fact, our analysis using the AR (1) model with dummy variables applied to the crisis period confirmed that the dynamic correlations were significantly lower during the debt crisis period than earlier. From investors' perspectives, this implies that opportunities for stock market diversification between Greece and the other six countries may have emerged since the occurrence of the sovereign debt crisis.

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Table 1. Summary of statistics on the stock index returns

Whole sample: (Jan 3, 2007 - Mar 31, 2011)

	Greece	Ireland	Italy	Spain	Germany	France	UK
Mean (percent)	-0.12	-0.11	-0.06	-0.03	0.01	-0.03	-0.01
Median (percent)	0.00	-0.05	0.01	0.05	0.08	0.00	0.00
Maximum (percent)	10.28	9.73	14.47	13.48	13.46	13.30	11.11
Minimum (percent)	-10.01	-13.96	-8.75	-9.59	-8.40	-9.47	-9.26
Std. Dev. (percent)	2.34	2.10	1.83	1.85	1.69	1.79	1.59
Skewness	-0.01	-0.43	0.35	0.40	0.33	0.35	0.16
Kurtosis	5.32	7.30	11.04	10.58	11.93	10.48	10.37
Jarque-Bera	235.55	840.00	2842.47	2533.45	3491.60	2462.23	2371.22
Num. of obs.	1046	1046	1046	1046	1046	1046	1046

Pre-crisis period (Jan 3, 2007 - Nov. 4, 2009)

	Greece	Ireland	Italy	Spain	Germany	France	UK
Mean (percent)	-0.08	-0.17	-0.09	-0.03	-0.03	-0.06	-0.03
Median (percent)	0.00	-0.10	0.00	0.05	0.06	-0.03	0.00
Maximum (percent)	10.28	9.73	14.47	12.78	13.46	13.30	11.11
Minimum (percent)	-10.01	-13.96	-8.75	-9.59	-8.40	-9.47	-9.26
Std. Dev. (percent)	2.21	2.35	1.96	1.90	1.90	1.95	1.80
Skewness	-0.22	-0.41	0.33	0.18	0.38	0.35	0.19
Kurtosis	6.45	6.55	10.65	9.32	10.83	9.95	9.27
Jarque-Bera	352.59	386.89	1719.75	1167.94	1805.65	1421.48	1152.23
Num. of obs.	700	700	700	700	700	700	700

Post-crisis period (Nov. 5, 2009 - Mar. 31, 2011)

	Greece	Ireland	Italy	Spain	Germany	France	UK
Mean (percent)	-0.20	0.00	-0.01	-0.02	0.07	0.02	0.04
Median (percent)	-0.19	0.00	0.07	0.02	0.10	0.05	0.03
Maximum (percent)	9.98	7.57	10.68	13.48	5.16	9.22	5.03
Minimum (percent)	-7.64	-5.96	-5.40	-6.87	-3.39	-4.71	-3.19
Std. Dev. (percent)	2.58	1.49	1.53	1.74	1.14	1.40	1.06
Skewness	0.28	-0.11	0.50	0.98	-0.03	0.39	0.02
Kurtosis	3.91	5.64	10.21	13.92	4.31	8.47	4.59
Jarque-Bera	16.41	100.95	764.05	1775.62	24.89	439.88	36.62
Num. of obs.	346	346	346	346	346	346	346

Note: Statistics for the difference of the logarithum on the daily stock indexes multipled by 100 are reported.

Table 2. AR-EGARCH models - Whole sample: (Jan 3, 2007 - Mar 31, 2011)

	Model by country													
	Greece		Ireland		Italy		Spain		Germany		France		UK	
Coefficient	AR(2)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)	
	estimate	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*
Mean Equation														
φ_0	-0.034	0.053	-0.038	0.0448	-0.040	0.0370	-0.018	0.040	0.032	0.035	-0.027	0.037	0.003	0.033
φ_1	0.059 *	0.033	0.037	0.0325	0.014	0.0346	0.009	0.032	0.012	0.034	-0.013	0.035	-0.017	0.034
φ_2	-0.052	0.032												
Variance Equation														
ω	-0.098 ***	0.024	-0.115 ***	0.025	-0.089 ***	0.024	-0.068 ***	0.023	-0.096 ***	0.025	-0.067 ***	0.023	-0.080 ***	0.024
α_1	0.157 ***	0.031	0.184 ***	0.035	0.131 ***	0.031	0.111 ***	0.030	0.143 ***	0.033	0.114 ***	0.031	0.114 ***	0.030
γ_1	-0.065 ***	0.017	-0.074 ***	0.023	-0.119 ***	0.018	-0.150 ***	0.019	-0.156 ***	0.023	-0.189 ***	0.025	-0.158 ***	0.022
β_1	0.985 ***	0.006	0.976 ***	0.007	0.982 ***	0.005	0.977 ***	0.006	0.973 ***	0.006	0.968 ***	0.007	0.977 ***	0.005
log likelihood	-2224.4		-2068.4		-1864.0		-1901.1		-1780.7		-1846.1		-1704.8	
Q(20)	31.243		22.548		20.080		9.395		14.283		13.613		11.578	
p-value	0.052		0.312		0.453		0.978		0.816		0.850		0.930	
Q²(20)	28.531		28.614		27.403		19.856		13.895		26.851		21.255	
p-value	0.097		0.096		0.124		0.467		0.836		0.140		0.382	

Note: ***, **, and * indicate statistical significance at 1%, 5%, and 10% level, respectively. *Q*(20) is the Ljung-Box statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals. *Q*²(20) is the Ljung-Box statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals squared.

Table 3. Dynamic Conditional Correlation estimates of the stock index returns (Greece versus six countries) - Whole sample: (Jan 3, 2007 - Mar 31, 2011)

	Asymmetric DCC estimates by country (versus Greece)																	
	Ireland			Italy			Spain			Germany			France			UK		
Coefficient	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*
a_1	0.116	***	0.038	0.015	***	0.006	0.015	**	0.007	0.010	*	0.005	0.002	***	0.006	0.033	***	0.007
b_1	0.479	**	0.196	0.974	***	0.013	0.960	***	0.022	0.988	***	0.009	0.974	***	0.012	0.936	***	0.018
g_1	-0.054		0.050	0.002		0.005	0.009		0.009	-0.002		0.002	0.001		0.005	0.018		0.014

Note: ***, **, and * indicate statistical significance at 1%, 5%, and 10% level, respectively.

Table 4. AR(1) models for the estimated DCC coefficients (Greece versus six countries) - Whole sample: (Jan 3, 2007 - Mar 31, 2011)

	DCC estimates by country (versus Greece)																	
	Ireland			Italy			Spain			Germany			France			UK		
Coefficient	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*	*estimate*		*SE*
δ_0	0.210	***	0.013	0.015	***	0.005	0.021	***	0.005	0.008	**	0.003	0.013	***	0.004	0.025	***	0.006
δ_1	0.583	***	0.025	0.976	***	0.007	0.966	***	0.008	0.986	***	0.006	0.980	***	0.007	0.959	***	0.009
ξ_1	-0.014	***	0.005	-0.002	**	0.001	-0.002	*	0.001	-0.002	***	0.001	-0.003	**	0.001	-0.005	**	0.002
R^2	0.361			0.967			0.944			0.990			0.973			0.938		

Note: ***, **, and * indicate statistical significance at 1%, 5%, and 10% level, respectively.

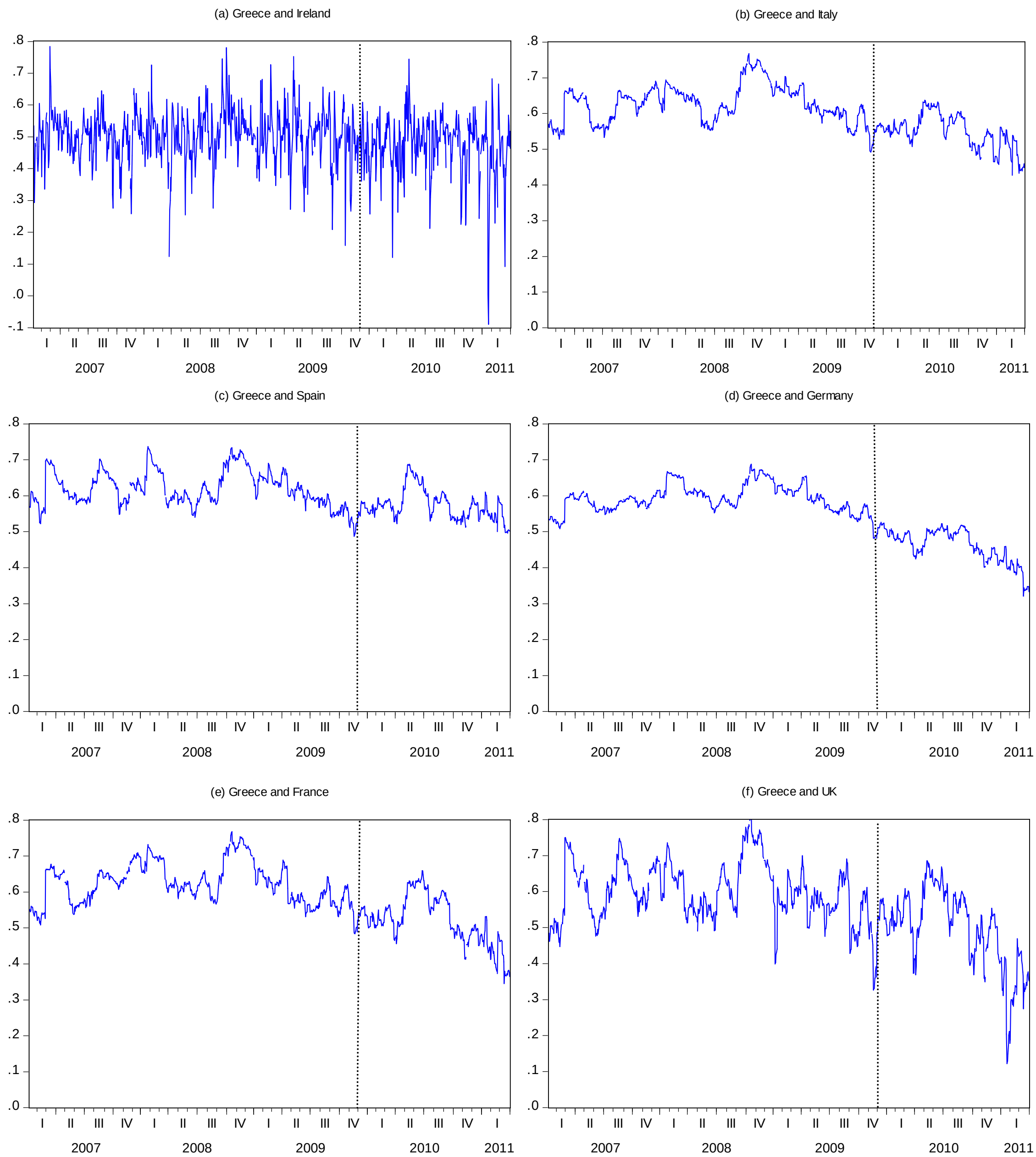

Fig 1. Daily DCCs: (a) DCC between Greece and Ireland stock indexes; (b) DCC between Greece and Italy stock indexes; (c) DCC between Greece and Spain stock indexes; (d) DCC between Greece and Germany stock indexes; (e) DCC between Greece and France stock indexes; (f) DCC between Greece and UK stock indexes

Note: Dotted lines in the figures indicate the beginning of the debt crisis period defined as November 5, 2009.