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CO-EXCEEDANCES IN EUROZONE STOCK MARKETS –A MULTINOMIAL LOGIT ANALYSIS OF CONTAGION

Abstract. *This paper examines contagion between stock markets of six Eurozone countries (France, Germany, Greece, Ireland, Italy, and Spain) during period from December 3, 2003 to January 27, 2012. A multinomial logistic model is applied to analyze contagion based on a measure of joint occurrences of extreme negative stock market returns (i.e. co-exceedances) while controlling for common and regional factors that affect all stock markets simultaneously. The results indicate that the DJI returns, the EUROSTOXX50 conditional volatility, and the EUR-USD exchange rate significantly impacted the probability of extreme negative returns in Eurozone stock markets. The probability of co-exceedance (or contagion) between the investigated Eurozone stock markets during the global financial crisis and the Eurozone debt crisis did not increase significantly.*

Keywords: *co-exceedance, Eurozone,* ***s****tock* markets, contagion, financial crisis, Eurozone debt crisis

JEL classification: **F21, F36, G15, H63**

1. Introduction

In the last decade Eurozone financial markets have witnessed several episodes of severe distress, the two most recent include the global financial crisis and the sovereign debt crisis, spreading across the countries and causing severe costs to financial market participants. It is of major concern of central banks and governments in conducting economic policy, preparing financial market regulation and performing financial market surveillance to separate between shocks that are transmitted across markets via channels that appear only during turbulent periods and shocks that are transmitted via channels or inter-linkages that exist in all states of the world (non-crisis or crisis periods). The former incidence of shock transmission is defined as contagion, while the latter as interdependence (see Forbes and Rigobon, 2002).

The literature suggests many definitions of contagion (see e.g., Forbes and Rigobon, 2001; Dornbusch et al., 2001; Corsetti et al., 2002; Pericoli and Sbracia, 2003; Baur and Lucey, 2009). Forbes and Rigobon (2001) provide one of the most commonly accepted definitions of contagion, namely the "shift contagion," which regards contagion as a shift or change in how shocks spread from one country (or asset class) to another during normal periods (pre-crisis) and how during crisis periods.

There are a range of statistical procedures to test for contagion in financial market. The most common methods to measure contagion include the adjusted correlation test of Forbes and Rigobon (2002), the outlier test of Favero and Giavazzi (2002), the co-exceedance test of Bae et al. (2003), and the threshold test of Pesaran and Pick (2004).

The method of Bae et al. (2003) possesses some features that render it very suitable for studying contagion in financial markets during turbulent times, like the global financial crisis. The method of Bae et al. (2003) measures contagion based on a measure of the joint occurrences of extreme stock market return (i.e., co-exceedances). Exceedance is defined as an occurrence of an extreme return in a stock market that is below (or above) a certain threshold. Co-exceedance is defined as a simultaneous occurrence of joint exceedances in two investigated stock markets. This measure circumvents problems associated with the correlation coefficient because co-exceedances are not biased in periods of high volatility and are not restricted to modeling linear phenomena (see Baur and Schulze, 2005; Dungey et al., 2005).

Co-exceedances in stock markets can be examined by a multinomial logistic regression. An important advantage of multinomial logistic analysis is that one can condition on attributes and characteristics of the exceedance events using control variables (or covariates) measured with information available up to the previous day. Following Bae et al. (2003), the strength of contagion between stock markets is then measured as the fraction of co-exceedance of extreme negative returns that are not explained by the covariates included in the model.

In this paper, the strength of contagion between stock markets of six Eurozone countries (France, Germany, Greece, Ireland, Italy, and Spain) is examined in a pair-wise manner, i.e. between pairs of observed stock markets. As we are interested in contagion during the turbulent times only (that occurred in the period from December 3, 2003 to January 27, 2012), we examine co-exceedance of large negative returns only. To separate contagion from interdependence, we include more covariates in the multinomial logistic model than did Bae et al. (2003), following suggestions in the empirical literature on contagion in the financial markets (see Dungey et al., 2005, 2007). Included are the U.S. stock market returns (proxied by the Dow Jones Industrial (DJI) returns), the conditional volatility of the average Eurozone stock market returns (proxied by the EUROSTOXX50 returns) modeled as EGARCH(1,1); Eurozone money market interest rate level (3-month EURIBOR); U.S. Treasury note yield changes; and returns on the Euro-U.S. dollar (EUR-USD) exchange rate. The response of probability estimates to the full range of values associated with different covariates are also computed and presented graphically to inspect whether the relationship between the probability of (co-) exceedances and covariates are linear or nonlinear. The paper also examines whether the most recent episodes of financial market distress (i.e., the global financial crisis and the Eurozone debt crisis) significantly impacted the probability of contagion in the investigated Eurozone stock markets.

2. Methodology

Exceedances in terms of extreme negative stock market returns in a particular country and pair-wise joint occurrence of extreme negative stock market returns can be modeled as a polytomous variable. The dependent polytomous variable at time t ($y_t; t = 1,...,T$) in the present paper can fall into one of three categories ($j = 1,2,3$): no exceedance in any of the pair-wise countries ($j = 1$); exceedance observed in one of the countries in the pair ($j = 2$); and co-exceedance ($j = 3$). This third category represents a simultaneous exceedance in both the countries, representing contagion. Probabilities associated with the events captured in the polytomous variables can then be estimated using a multinomial logistic model (Bae et al., 2003). An advantage of multinomial logistic analysis is that we can condition on attributes and characteristics of the exceedance events using control variables (explanatory variables or covariates) that are measured using information available up to the previous day. The multinomial logit model assumes that the probability of observing category j (of the three possible categories) in the dependent polytomous variable, P_j, is given by Equation (1) (Greene, 2003)

$$P_j = \Pr(y_t = j) = \frac{\exp(\beta_j' \boldsymbol{x})}{1 + \sum_{k=2}^{3} \exp(\beta_j' \boldsymbol{x})}, \qquad (1)$$

where $\boldsymbol{x}$ is a $T \times n$ matrix of covariates (with n being the number of different covariates) and β the vector of coefficients (including a constant) of a particular category associated with the covariates.[1] The covariates included in the model are the U.S. stock market returns proxied by returns on the EUROSTOXX50 index; the conditional volatility of the average Eurozone stock market returns, proxied by

[1]To separate contagion from interdependence, it is important to identify common and regional factors that impact all countries simultaneously (Dungey et al., 2005). A failure to model common and regional factors may result in tests of contagion being biased toward a positive finding of contagion.

the EUROSTOXX50 returns, modeled as EGARCH(1,1)[2]; the Eurozone money market interest rate level (3-month EURIBOR); 10-year U.S. Treasury note yield changes; and returns on the EUR-USD exchange rate. Because we also want to answer the question whether the probability of contagion increases in a crisis period compared to a non-crisis period, we also include two dummy variables.[3] The first dummy variable represents the crisis period from September 16, 2008[4] to April, 22, 2010 and the second represents the crisis period from April 23, 2010 to January 27, 2012[5].

Coefficients β are specific to each category, so that there are $j \times n$ coefficients to be estimated. The coefficients are not all identified unless we impose normalization (see Greene, 2003). Normalization in the present paper is achieved by setting the coefficient of the first category ($j = 1$) to be zero. All regression coefficients of Equation (1) are thus calculated with respect to the first category (category 1) as a base category.

The model is estimated using maximum likelihood with the log-likelihood function for a sample of t observations given by

$$\ln L = \sum_{t=1}^{T} \sum_{j=1}^{3} d_{tj} \log(P_{tj}) , \qquad (2)$$

where d_{tj} is a dummy variable that takes a value one if observation t takes the *j*th category and zero otherwise. Because P_{tj} is a nonlinear function of the β s, an iterative Newton-Rahpson's estimation procedure is applied. Goodness-of-fit is measured using the pseudo-R^2 of McFadden (1974) where both unrestricted (full model) likelihood, L_{ω}, and restricted(constants only) likelihood, L_{Ω}, functions are compared

[2]Nelson's (1991) EGARCH model stipulates that negative and positive returns have different impacts on volatility.

[3]DJI returns, logaritmic changes in the U.S. Treasury note yields and the EUR-USD exchange rate (log) returns are included as a proxy for global macroeconomic developments and the associated inflation, liquidity, and credit risks (see e.g., Forbes and Rigobon, 2002; Dungey et al., 2005; Metiu, 2011). The region-specific factors that capture local financial market conditions are the Eurozone money market rate and its conditional volatility. As argued by Dungey et al. (2007) the stock markets should not be studied in isolation, because there are interaction effects across different asset classes. In their study, Bae et al. (2003) included only conditional volatility of the stock market, exchange rate returns, and the interest rate level.

[4]On September 16, 2008 the investment bank Lehman Brothers collapsed and started the global financial crisis.

[5]On April 23, the Greek government requested a bailout from the EU/IMF. We take this date as the start of the sovereign debt crisis in the Eurozone.

$$pseudoR^2 = 1 - \frac{\log L\omega}{\log L_\Omega}. \quad (3)$$

After calculating regression coefficients, the probabilities of each of the three categories, P_j, are computed by evaluating the covariates at their unconditional values

$$P_j = \frac{\exp(\beta_j' x^*)}{1 + \sum_{k=2}^{3} \exp(\beta_k' x^*)}, \quad (4)$$

where x^* is the vector of the unconditional mean values of the covariates. Because the coefficients in a multinomial logit model are difficult to interpret, following Greene (2003) and Bae et al. (2002), the marginal changes in probability for a given unit change in the independent covariate (i.e., marginal effects) are calculated and tested whether they are significantly different from zero. The marginal effects (δ_j) are given by the following equation (Greene, 2003)

$$\delta_j = \left.\frac{\partial P_j}{\partial x}\right|_{x=x^*} = P_j \left[\beta_j - \sum_{k=1}^{3} P_k \beta_k \right]\Bigg|_{x=x}. \quad (5)$$

3. Data and empirical results

Co-exceedances in the returns of six Eurozone countries, listed in Table 1, are analyzed for the period from December 3, 2003 – January 27, 2012. The stock indices returns were calculated as the differences in the logarithms of the daily closing prices of indices ($\ln(P_t) - \ln(P_{t-1})$, where P is an index value). The stock indices included are: the Athens Composite Index (ACI, for Greece), CAC40 (for France), DAX (for Germany), ISEQ (for Ireland), FTSEMIB (for Italy), and IBEX35 (for Spain). Days with no trading in any of the observed market were left out. Returns (and all other variables, i.e. covariates) were calculated as two-day rolling-average logarithmic returns (or changes) in order to control for the fact of the different open hours of the markets on which the variables in the model are formed[6]. The data for stock indices is Yahoo! Finance[7]. Table 1 presents some descriptive statistics of the data.

[6]The same approach is used by Forbes and Rigobon (2002).

Table 1: Descriptive statistics of stock indices returns

	Min	Max	Mean	Std. deviation	Skewness	Kurtosis	Jarque-Bera statistics
ACI	-0.1192	0.1113	-0.000555	0.01823	-0.0737	7.5269	1640.34
CAC40	-0.0947	0.1059	-0.000026	0.01577	0.1642	10.4452	4440.75
DAX	-0.0743	0.108	0.0002778	0.0153	0.1162	9.4645	3345.76
ISEQ	-0.1396	0.09733	-0.000241	0.01726	-0.5573	9.8403	3840.51
FTSE-MIB	-0.0997	0.1087	-0.000284	0.01618	-0.1569	9.6681	3563.07
IBEX35	-0.1160	0.1348	-0.000084	0.01601	0.0099	12.0721	6580.83

Notes: The Jarque-Bera statistics: *** indicate that the null hypothesis (of normal distribution) is rejected at a 1% significance level, ** that null hypothesis is rejected at a 5% significance level and * that the null hypothesis is rejected at a 10% significance level. ACI = Athens Composite Index.

All series display significant leptokurtic behavior as evidenced by the large kurtosis with respect to the Gaussian distribution. The Jarque-Bera test rejected the hypothesis of normally distributed time series. We also tested for stationarity of time series by the Augmented Dickey-Fuller (ADF) test, Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests and the results lead to conclusion of no unit root in returns series[8]. Table 2 reports Pearson's correlation coefficients of the two-day rolling-average returns of stock indices. The greatest correlation is observed between the DAX-CAC40 and CAC40-FTSE100, while the Athens Composite index is the least correlated with other indices.

Table 2: Pearson's correlation of Eurozone stock market returns

	ACI (Greece)	CAC40 (France)	DAX (Germany)	ISEQ (Ireland)	FTSEMIB (Italy)	IBEX35 (Spain)
ACI	1					
CAC40	0.6177	1				
DAX	0.5810	0.9332	1			
ISEQ	0.5595	0.7619	0.7093	1		
FTSE-MIB	0.6255	0.9171	0.8633	0.7097	1	
IBEX35	0.6236	0.8926	0.8350	0.6900	0.8880	1

Notes: All the correlation coefficients are significantly different from zero. ACI = Athens Composite Index.

Results of the model multinomial model (1) are reported in Tables 3a and 3b. Notably, the DJI returns, conditional volatility of the EUROSTOXX50 returns, the EUR-USD, and for some pair-wise stock markets also time dummies are significantly different from zero. The pseudo-R^2 is between 0.32 and 0.48. The 10-year Treasury note yield (daily logarithmic) changes, and the euro money market

[7] The data series for the 3-month EURIBOR and the EUR-USD dollar exchange rate were obtained from the web page of Deutsche Bundesbank. The data series of EUROSTOXX50 and the 10-year U.S. Treasury note yields are from Yahoo! Finance.
[8]The results are not presented here, but can be obtained from the author.

rates do not significantly affect the log odds of (co-)exceedances in the Eurozone stock markets. From the data in Table 3a, it follows that for the stock indices ACI-CAC40, a 1 unit (i.e., 1 %) increase in the DJI returns is associated with a 1.42[9] drop in the relative log odds of outcome 2 (i.e., exceedance in one of the stock markets) versus outcome 1 (i.e., no co-exceedance in any of the two observed stock markets), and even a larger drop of relative log odds (of 2.22) of outcome 3 (i.e., co-exceedance or contagion) versus the outcome 1. A one unit increase in the conditional volatility of EUROSTOXX50 returns is associated with a 0.43 increase in relative log odds of outcome 2 and a 0.45 increase of log odds of outcome 3 versus the outcome 1. Appreciation of EUR against USD is associated with a 0.56 drop in log odds of outcome 2 versus outcome 1, and a 1.04 drop of log odds of outcome 3 versus the outcome 1. The same signs of the regression coefficients for DJI returns, conditional volatility of the EUROSTOXX50 returns and the EUR-USD can be observed also for other stock indices pairs. Time dummies are significantly different from zero only for some pair-wise observed stock indices. The log odds of outcome 3 (i.e. co-exceedance or contagion between the markets) can be observed to have increased for the ACI-ISEQ, CAC40-ISEQ, and ISEQ-FTSEMIB stock indices during both crisis periods (i.e. during the global financial crisis and during the Eurozone debt crisis). The log odds of outcome 2 (i.e. exceedance in only one market) increased during both crisis period for the CAC40-FTSEMIB, ISEQ-FTSEMIB, ISEQ-IBEX35 and FTSEMIB-IBEX35 indices.

Table 3a: Estimates of the multinomial logit regression model (1) for specific pair-wise observed stock market returns

	ACI-CAC40	ACI-DAX	ACI-ISEQ	ACI-FTSEMIB	ACI-IBEX35	CAC40-DAX	CAC40-ISEQ	CAC40-FTSEMIB
Outcome 2								
Constant	-4.027***	-4.622***	-4.363***	-4.413***	-3.772***	-6.747***	-5.275***	-5.817***
DJI (returns)	-142.05***	-149.48***	-121.93***	-131.81***	-137.17***	-197.11***	-174.74***	-187.64***
cond. volatility of EUROSTOXX50 returns	4332.9***	4484.7***	3252.6***	4495.7***	4047.8***	3034.4***	2733.3***	1988.8*
EURIBOR (level)	-0.169	-0.281**	0.256**	-0.207	-0.204	-0.226	0.508 ***	0.091
USA 10y T.N. yields level	0.0129	0.2436	-0.0603	0.0339	-0.0066	0.3982	-0.1569	-0.0003
EUR-USD returns	-56.121***	-58.962***	-37.492*	-64.742***	-88.234***	-157.28***	-37.769*	-62.717**
Crisis period 1	0.544	0.592	0.769*	0.936*	0.339	0.624	0.854	1.323**
Crisis period 2	0.720	0.688	0.695	1.307**	0.709	1.465*	1.087	1.939**
Outcome 3								
Constant	-9.018***	-4.651***	-10.0466**	-8.2805***	-7.9510***	-4.6770***	-10.068***	-7.1757***
DJI (returns)	-222.24***	-215.20***	-188.55***	-198.08***	-193.92***	-261.64***	-259.56***	-237.15***
cond. volatility of EUROSTOXX50 returns	4524.6***	5657.15***	2482.36**	3464.73***	4111.31***	5548.25***	3329.04**	4142.39**
EURIBOR (level)	0.2102	0.2394	0.4654**	0.0678	-0.0113	0.0491	0.4335**	.07973
USA 10y T.N. yields level	0.2891	-0.7129*	0.4366	0.2755	0.3126	-0.3853	0.4662	0.0803
EUR-USD returns	-104.24***	-117.45***	-94.016***	-163.14***	-176.56***	-51.99*	-50.402*	-99.828***
Crisis period 1	1.1897	-0.2857	2.4892***	1.5336*	0.7992	-05589	1.7088**	0.9396
Crisis period 2	2.5750	-0.2015	3.0279***	2.1706**	1.5773	-0.0798	2.7998***	2.0661**
Log likelihood	-375.88	-375.82	-423.85	-367.22	-388.90	-279.28	-355.82	-298.70
LR chi (14)	462.80	471.08	389.81	480.13	448.80	523.78	480.37	484.94
Pro>chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo-R^2 (McFadden)	0.3810	0.3853	0.3150	0.3953	0.3659	0.4839	0.4030	0.4480

[9] 0.01*142.05=1.42, as in the data a 1% is expressed as 0.01.

Notes: Estimates of the regression coefficients of model (1) are given. Crisis 1 is a time dummy for the first crisis period (September 16, 2008[10] –April, 22, 2010) and Crisis 2 is a time dummy of the second crisis period (from April 23, 2010[11] – August 31, 2011). Outcome 1 (no (co-)exceedance) is the base category. Outcome 2 presents the results of model (1) for category 2 (i.e.,exceedance in one country only), whereas outcome 3 presents the results of model (1) for category 3 (i.e. co-exceedance). ***/**/* denote the 1%, 5%, and 10% significance of the rejection of the null hypothesis that the regression coefficient is equal to 0, based on z-statistics. LR chi(14) reports the likelihood-ratio chi-square test (at 14 degrees of freedom) that for both equations (i.e., for outcome 2 and outcome 3) at least one of the covariate's coefficients is not equal to zero. Prob.>chi2 reports the probability of getting a LR test statistic as extreme as, or more so, than the observed under the null hypothesis (i.e., that all of the regression coefficients of both models, i.e. for outcome 2 and outcome 3, are simultaneously equal to zero).

Table 3b: Estimates of the multinomial logit regression model (1) for specificpair-wise observedstock market returns

	CAC-IBEX35	DAX-ISEQ	DAX-FTSEMIB	DAX-IBEX35	ISEQ-FTSEMIB	ISEQ-IBEX35	FTSEMIB-IBEX35
Outcome 2							
Constant	-4.864***	-4.351***	-6.002***	-6.252***	-5.047***	-5.347***	-5.229***
DJI (returns)	-176.31***	-187.48***	-192.85***	-195.72***	-150.06***	-161.02***	-144.32***
cond. volatility of EUROSTOXX50 returns	1916.6*	3702.6***	3402.2***	3824.5***	1861.1**	1497.4*	922.5
EURIBOR (level)	0.1258	0.3519***	-0.1220	-0.1529	0.5820***	0.48271***	0.1300
USA 10y T.N. yields level	-0.161	-0.228	0.308	0.410	-0.267	-0.068	-0.078
EUR-USD returns	-48.023*	-57.949***	-110.292***	-139.175***	-65.749***	-71.349***	-117.371***
Crisis period 1	0.5038	0.2708	0.2247	0.0405	1.2238**	1.0570**	1.4080**
Crisis period 2	1.3893*	0.0929	1.1411	1.2137*	1.5858**	1.4533**	1.8027**
Outcome 3							
Constant	-6.267***	-8.048***	-4.968***	-3.705***	-9.617***	8.085***	-5.848***
DJI (returns)	-230.97***	-268.08***	-237.56***	-258.39***	-231.43***	-230.86***	-213.19***
cond. volatilityof EUROSTOXX50 returns	4065.7***	3767.1***	4497.7***	5087.2***	2513.6**	3257.2***	3474.2***
EURIBOR (level)	-0.0772	0.4026**	0.0581	-0.0732	0.3343*	0.2476	-0.0976
USA 10y T.N. yields level	0.1272	-0.0010	-0.4680	-0.5841	0.4281	0.2460	-0.0101
EUR-USD returns	-118.323***	-56.374 *	-98.215***	-117.48***	-90.445***	-117.21***	-151.136***
Crisis period 1	-0.0111	1.2533	0 .6876	-0.7594	2.2862***	0.8497	0.3635
Crisis period 2	1.0896	1.3145	0.8755	-0.7190	2.8470***	1.41633	1.2676
Log likelihood	-310.96	-356.31	-308.87	-321.47	-366.12	-382.56	-318.74
LR chi (14)	445.07	501.95	499.97	517.71	464.54	445.19	452.26
Pro>chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo-R^2 (McFadden)	0.4171	0.4133	0.4473	0.4460	0.3882	0.3678	0.4150

Notes: See notes for Table 3a.

Greene (2003) warns about the interpretation of the multinomial logit coefficients and advocates the calculation of marginal effects for an economic interpretation of the regression coefficients. The marginal effects and probabilities of outcomes are reported in Tables 4a and 4b.

[10]On September 16, 2008, the investment bank Lehman Brothers collapsed and started the global financial crisis.
[11]On April 23, the Greek government requested a bailout from the EU/IMF. We take this date as the start of the sovereign debt crisis in Eurozone.

Evidently, probability of no (co-)exceedance in stock markets is higher than probability of exceedance (outcome 2) or co-exceedance (outcome 3) (see Probabilities 1 in Tables 4a and 4b). The probability of exceedance ranges between 0.0261 (for CAC40-IBEX35) and 0.0584 (for ACI-ISEQ), while the probability of co-exceedance (or contagion) ranges between 0.0209 (for ACI-ISEQ) and 0.037 (for CAC40-IBEX35). These probabilities are calculated without controlling for covariates, though.[12] As noted, to separate contagion from interdependence, it is important to control for common and regional factors that impact all countries simultaneously. This reduces the probabilities of observing outcomes 2 and 3 (see Probabilities 2 in Tables 4a and 4b). The probabilities of outcome 2 now range between 0.0066 (for CAC40-DAX) and 0.0353 (for ACI-ISEQ), and probabilities of outcome 3 between 0.0018 (for ACI-DAX) and 0.005 (for CAC40-IBEX35). Comparing the Probabilities 2 with the Pearson's correlation coefficients (Table 2) it becomes evident that the probability of exceedance or co-exceedance is the smallest for the stock markets that are the most correlated (CAC40-DAX and CAC40-FTSEMIB).

Table 4a: Marginal effects and probabilities of outcomes for particular pair-wise observed stock markets

	ACI-CAC40	ACI-DAX	ACI-ISEQ	ACI-FTSEMIB	ACI-IBEX35	CAC40-DAX	CAC40-ISEQ	CAC40-FTSEMIB
Outcome 2								
DJI (returns)	-3.5182***	-3.8213***	-4.1307***	-2.7664***	-3.4485***	-1.2908***	-3.2699***	-1.6606***
cond. volatility of EUROSTOXX50 returns	107.44***	114.69***	110.45***	94.54***	101.88***	19.83**	51.19***	17.55*
EURIBOR (level)	-0.0042	-0.0072**	0.0087**	-0.0044	-0.0052	-0.0015	0.0095***	0.0008
USA 10y T.N. yields level	0.0003	0.0063	-0.0021	0.0007	-0.0002	0.0026	-0.0030	-5.64e-06
EUR-USD returns	-1.3891	-1.5057***	-1.2665*	-1.3550***	-2.2144***	-1.0339***	-0.7071*	-0.5544**
Crisis period 1	0.0158	0.0183	0.0320	0.0264	0.0094	0.0051	0.0208	0.0186
Crisis period 2	0.0213	0.0214	0.0271	0.0404	0.0216	0.0156	0.0275	0.0328
Outcome 3								
DJI (returns)	-0.4754***	-0.3873**	-0.5237***	-0.5156***	-0.5407***	-0.9976***	-0.6718***	-0.8704***
cond. volatility of EUROSTOXX50 returns	9.5980**	10.1530	6.7292	8.8945*	11.3788**	21.185***	8.5910**	15.2456**
EURIBOR (level)	0.0005	0.0005	0.0013*	0.0002	-0.0000	0.0002	0.0011*	0.0003
USA 10y T.N. yields level	0.0006	-0.0013*	0.0012	0.0007	0.0009	-0.0015	0.0012	0.0003
EUR-USD returns	-0.2235**	-0.2124**	-0.2635**	-0.4272***	-0.4950***	-0.1952	-0.1302	-0.3669**
Crisis period 1	0.0039	-0.0005	0.0184	0.0069	0.0029	-0.0018	0.0083	0.0046
Crisis period 2	0.0143	-0.0004	0.0269	0.0120	0.0074	-0.0004	0.0207	0.0153
Probabilities 1								
Outcome 1	0.9239	0.9228	0.9208	0.9239	0.9223	0.9359	0.9265	0.9359
Outcome 2	0.0521	0.0542	0.0584	0.0521	0.0553	0.0282	0.0469	0.0282
Outcome 3	0.0240	0.0229	0.0209	0.0240	0.0224	0.0360	0.0266	0.0360
Probabilities 2								
Outcome 1	0.9723	0.9718	0.9619	0.9758	0.9712	0.9895	0.9782	0.9873
Outcome 2	0.0255	0.0263	0.0353	0.0215	0.0259	0.0066	0.0192	0.0090
Outcome 3	0.0022	0.0018	0.0029	0.0026	0.0028	0.0038	0.0026	0.0037

Notes: Probabilities 1 are probabilities of outcomes when we do not control for covariates. Probabilities 2 are probabilities of outcomes after controlling for the covariates and are calculated by Equation (4).****/**/*denote the 1%, 5%, 10% significance of the rejection

[12] If outcomes were independent, then the probabilities of co-exceedances between all sovereign bond markets investigated pair-wise would be $0.05^2 = 0.0025$.

of the null hypothesis that the marginal effect of the covariate is equal to 0 based on z-statistics. The reported marginal effects of the time dummy covariates (Crisis period 1, Crisis period 2) show by how much the probability of observing outcome 2 (outcome 3) increases when the value of the time dummy variable changes from 0 to 1.

Table 4b: Marginal effects and probabilities of outcomes for particular pair-wise observed stock markets

	CAC-IBEX35	DAX-ISEQ	DAX-FTSEMIB	DAX-IBEX35	ISEQ-FTSEMIB	ISEQ-IBEX35	FTSEMIB-IBEX35
Outcome 2							
DJI (returns)	-1.7721***	-3.6633***	-2.1703***	-2.4098***	-3.0009***	-3.5860***	-1.6297 ***
cond. volatility of EUROSTOXX50 returns	19.1848	72.4099***	38.2785***	47.0885***	37.2392**	33.2658*	10.3098
EURIBOR (level)	0.00128	0.0069***	0-.0014	-0.0019	0.0117***	0.0108***	0.0015
USA 10y T.N. yields level	-0.0016	-0.0045	0.0035	0.0051	-0.0054	-0.0015	-0.0009
EUR-USD returns	-0.4799*	-1.1334**	-1.2425 ***	-1.7159***	-1.3155***	-1.5878***	-1.3265***
Crisis period 1	0.0060	0.0057	0.0027	0.0005	0.0361	0.0332	0.0261
Crisis period 2	0.0217	0.0018	0.0183	0.0220	0.0509	0.0504	0.0370
Outcome 3							
DJI (returns)	-1.1313***	-0.0021***	-0.6997***	-0.7062***	-0.6558***	-0.7262***	-0.9342***
cond. volatility of EUROSTOXX50 returns	19.9741***	7.8184**	13.2559**	13.9058***	7.1090*	10.3031**	15.2972**
EURIBOR (level)	-0.0004	0.0008*	0.0002	-0.0002	0.0009	0.0008	-0.0004
USA 10y T.N. yields level	0.0006	7.49e-06	-0.0014	-0.0016	0.0012	0.0008	-0.0001
EUR-USD returns	-0.5817 ***	-0.1169	-0.2882**	-0.3193**	-0.2559**	-0.3695***	-0.6615***
Crisis period 1	-0.0001	0.0041	0.0026	-0.0017	0.0155	0.0034	0.0016
Crisis period 2	0.0074	0.0043	0.0033	-0.0017	0.0229	0.0068	0.0080
Probabilities 1							
Outcome 1	0.9369	0.9239	0.9333	0.9296	0.9296	0.9244	0.9353
Outcome 2	0.0261	0.0521	0.0334	0.0407	0.0407	0.0511	0.0292
Outcome 3	0.0370	0.0240	0.0334	0.0297	0.0297	0.0245	0.0355
Probabilities 2							
Outcome 1	0.9848	0.9779	0.9856	0.9847	0.9766	0.9739	0.9841
Outcome 2	0.0102	0.0200	0.0114	0.0125	0.0205	0.0229	0.0115
Outcome 3	0.0050	0.0021	0.0030	0.0028	0.0029	0.0032	0.0044

Notes: See notes for Table 4a.

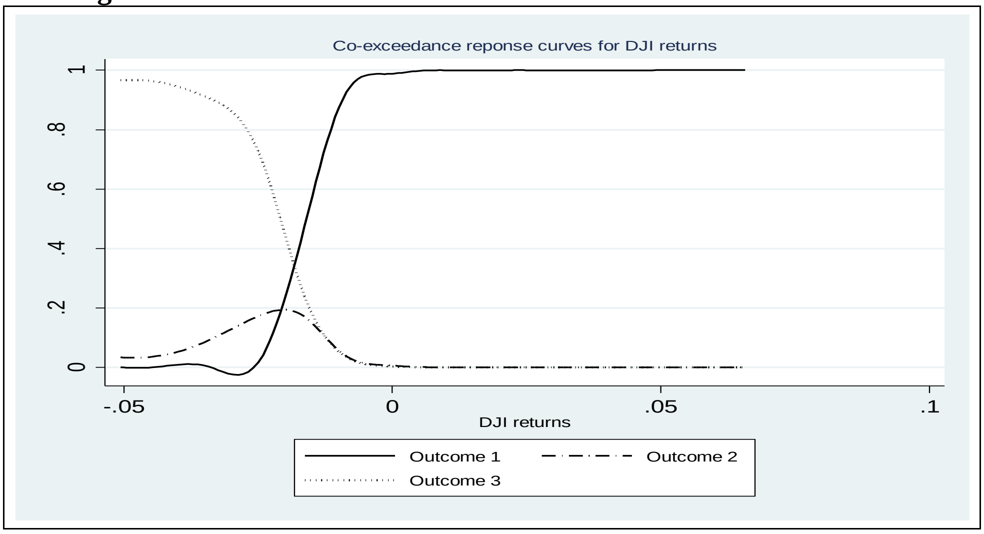
Turning now to marginal effects of specific covariates, DJI returns, EUROSTOXX50 conditional volatility, and EUR-USD exchange rate significantly impact the probability of extreme negative returns in stock markets. Positive (negative) DJI returns reduce (increase) the probability of extreme negative returns in investigated Eurozone stock markets. Increased conditional volatility of EUROSTOXX50 returns increases and the increase in the EUR-USD exchange rate (i.e., appreciation of the EUR against the USD) significantly reduces the probability of extreme negative returns in Eurozone stock markets. The Eurozone money market interest rate, U.S. Treasury note yield dynamics and the time dummies do not significantly impact the probability of extreme returns in Eurozone's stock markets.

The responsiveness of the co-exceedance variable to shocks in the U.S. stock markets is significant for all multinomial logit models of pair-wise observed Eurozone stock markets. It is interesting to note, that the one unit decrease in U.S. returns increases more the probability of exceedance than the probability co-exceedance thus indicating that some Eurozone stock markets react more intensely to the shocks in the U.S. stock market than the other markets do. For the ACI-

ISEQ indices the marginal coefficient is the highest in value. A one percent fall of DJI index increases the probability of exceedance in ACI or ISEQ returns by 4.13%, while the probability of co-exceedance is increased by 0.52%.

The marginal effects in Tables 4a and 4b must be read with caution, as they are calculated at covariates' unconditional means only. As argued by Greene (2003), calculating the marginal effects at covariates' means only can gives an incomplete picture if the probabilities of the dependent variable are non-linear functions of covariates. Therefore, the response of probability estimates to the full range of values of DJI returns is computed and presented graphically in Figure 1. The figure reveals that relationship between the probability of co-exceedance and the U.S. returns is not linear. For example, for the CAC40-DAX the probability of co-exceedance increases rapidly if the U.S. stock market falls more than approximately 2% in a day. If returns in U.S. stock market are positive, the probability of (co-)exceedance in CAC40-DAX drops to zero[13].

Figure 1: Co-exceedance response curves of the CAC40-DAX returns to the full range of returns of the DJI

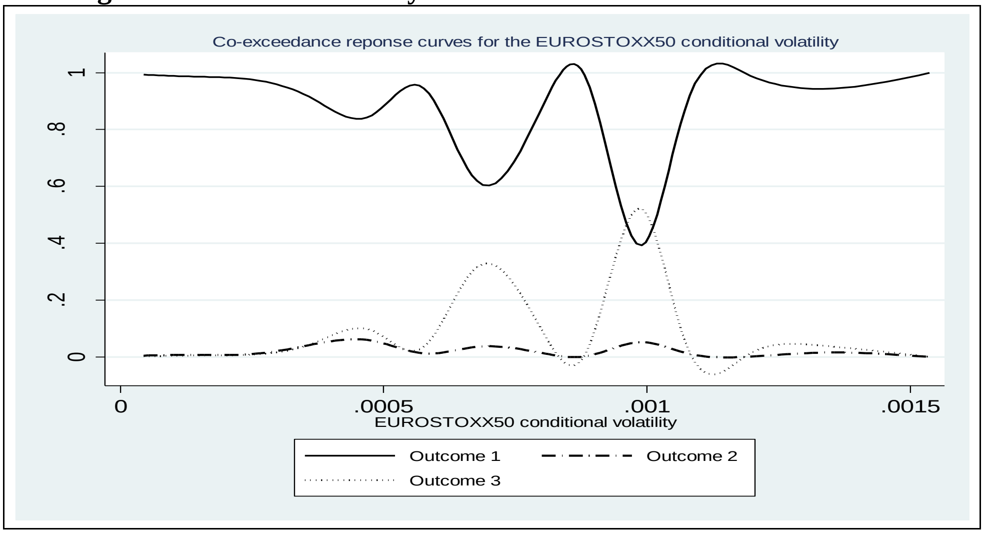


Conditional volatility of the EUROSTOXX50 returns, taken in this paper as a proxy for the volatility in the Eurozone stock markets, significantly impacts the probability of exceedance in all but four stock market pairs: CAC40-FTSEMIB, CAC40-IBEX35, ISEQ-IBEX35, and FTSEMIB-IBEX35. Similarly, the volatility of the EUROSTOXX50 returns significantly affects the probability of co-exceedance in all but four markets: ACI-DAX, ACI-ISEQ, ACI-FTSEMIB, and ISEQ-FTSEMIB. As evident from Figure 2, the probability of simultaneous extreme fall in CAC40 and DAX prices is the highest when daily conditonal

[13] Co-exceedance response curves for other stock indices pairs are not presented in order to save space, but their plots resemble the one in Figure 1.

volatility (variance) of EUROSTOXX54 returns is around 0.001[14]. The relationship between the probability of (co-)exceedance and the conditional volatility of the EUROSTOXX50 returns is non-linear.

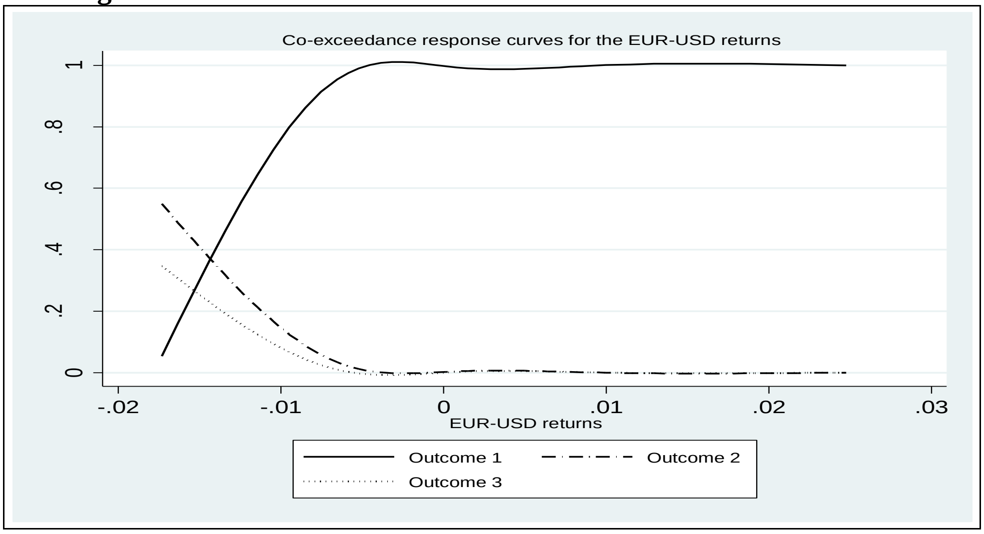
Figure 2: Co-exceedance response curves of the CAC40-DAX returns to the full range of conditional volatility of EUROSTOXX50 returns



Appreciation of the euro against the U.S. dollar reduces the probability of exceedance in all but four pair-wise observed Eurozone stock markets: ACI-CAC40, ACI-ISEQ, CAC40-ISEQ, and CAC40-IBEX35. Similarly, the probability of co-exceedance is reduced in case of EUR appreciation in all but three stock markets: DAX-ISEQ, CAC40-DAX, and CAC40-ISEQ. If EUR depreciates in a day by more than 1 percent the probability of (co-)exceedance in the Eurozone stock markets rapidly increases (see Figure 3 for the case of CAC40-DAX).

[14] Very similar graphs could be observed also for other pairs of stock indices.

Figure 3: Co-exceedance response curves of the CAC40-DAX returns to the full range EUR-USD returns



To answer whether the most recent episodes of financial market distress (i.e., the global financial crisis and the Eurozone debt crisis) significantly impacted the probability of contagion in the investigated Eurozone stock markets, the time dummies need to be examined. As evident from Tables 4a and 4b, the marginal effects of time dummies are not significantly different from zero. The positive signs of the time dummies do indicate that the probability of contagion did increase especially during the third period for some stock markets. For example, the probability of co-exceedance or contagion between the Greek and the Irish stock market increased by 0.0269 (or 2.7%) during the period of Eurozone debt crisis as compared to the previous period, yet the marginal effect is not significant, so according to our definition of contagion, there was no (statistically significant) contagion during the most recent episodes of financial market distress (i.e., the global financial crisis and the Eurozone debt crisis).

4. Conclusion

The present paper examined contagion between six Eurozone stock markets during the period from December 3, 2003 to January 27, 2012 in a pair-wise manner. Contagion is defined as an occurrence of large negative returns (i.e., co-exceedances) jointly in two stock markets. A multinomial logit was applied to control for common and regional factors that affect all stock market simultaneously.

We found that the DJI returns, the EUROSTOXX50 conditional volatility, and the EUR-USD exchange rate significantly impact the probability of extreme negative returns in Eurozone stock markets. Positive (negative) DJI returns reduce (increase) the probability of extreme negative returns in all investigated Eurozone stock markets. Increased conditional volatility of EUROSTOXX50 returns increases and the increase in the EUR-USD exchange rate (i.e., appreciation of the EUR against the USD) significantly reduces the probability of extreme negative returns in Eurozone stock markets. The Eurozone money market interest rate, U.S. Treasury note yield dynamics and the time dummies did not significantly impact the probability of extreme returns in Eurozone's stock markets. The probability of co-exceedance or contagion between the investigated Eurozone stock markets during the global financial crisis and the Eurozone debt crisis did not increase significantly.

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