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To cite this article: Silvo Dajčman (2014) Was there a contagion between major European and Croatian stock markets? An analysis of co-exceedances, Economic Research-Ekonomiska Istraživanja, 27:1, 155-168, DOI: [10.1080/1331677X.2014.952110](https://doi.org/10.1080/1331677X.2014.952110)

To link to this article: <http://dx.doi.org/10.1080/1331677X.2014.952110>



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Published online: 15 Sep 2014.



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Was there a contagion between major European and Croatian stock markets? An analysis of co-exceedances

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(Received 26 May 2012; accepted 16 January 2013)

This article examines extreme returns co-movement and contagion between the Croatian and 10 European stock markets during major financial market distress periods in the period from end of 2003 until start of 2012. The extreme return co-movement analysis is based on analysis of coincidences of extreme return shocks (co-exceedances; extreme returns are defined as lower 5% daily returns in the empirical return distributions) across investigated countries. I found that the first instances of co-exceedances between the Croatian and the observed European stock markets occurred in the 2007, during the subprime mortgage crisis as the predecessor of the global financial crisis. With the start of the global financial crisis, the count of co-exceedances across all observed pairs of stock markets markedly increased. In order to separate contagion from interdependence, I further applied a multinomial logistic function, that enabled me to control for common world and regional factors that affected all investigated stock markets simultaneously. In controlling for these factors I found that the increase in the count of negative return co-exceedances between the Croatian and major European stock markets during the global financial crisis and the eurozone debt crisis cannot be attributed to contagion.

Keywords: stock markets; Croatia; co-exceedance; contagion; financial crisis

JEL classification: F21, F36, G15, H63

1. Introduction

In recent years, world and Croatian stock markets have witnessed several episodes of severe distress, with the two most recent including the global financial crisis and the sovereign debt crisis. These shocks spread quickly across financial markets, countries and spread also to the real economy thus causing severe costs not only to financial market participants but wider. Whether a propagation of shocks across markets is a result of interdependence between markets (i.e. tight economic and financial linkages that exist between countries during all states of the world, for example during crisis and non-crisis periods) or a result of contagion (in this case shocks are propagated through channels that appear only during turbulent periods¹) is a matter of scientific evaluation. The results of this evaluation are important from the economic policy perspective as the later

While there are a range of statistical procedures to test for contagion in financial market (the most common are the adjusted correlation test of Forbes and Rigobon (2002), the co-exceedance test of Bae, Karolyi, & Stulz (2003), the outlier test of

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Favero and Giavazzi (2002), and the threshold test of Pesaran and Pick (2003)), the method that is very suitable to study contagion in stock markets during extreme market events is the method of Bae et al. (2003).

The method of Bae et al. (2003) incorporates the extreme value concept of exceedance returns and measures contagion based on joint occurrences of extreme stock market return (i.e. co-exceedance). The method applies a multinomial logistic analysis that allows us to 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.

There are several papers investigating shock transmission between the Croatian and developed stock markets, including Sajter and Ćorić (2009), Kunovac (2011), and Dajčman (2013b), yet none of them applies a formal test of contagion discussed above. This article examines the strength of contagion between Croatian and stock market of 10 other European stock markets (namely of Austria, England, France, Germany, Greece, Hungary, Ireland, Italy, Russia and Spain) in a pair-wise manner, i.e. between two stock markets at a time. As I am interested in contagion during the turbulent times only (that occurred in the period from December 3, 2003 to January 27, 2012), I examine co-exceedance of large negative returns only. To separate contagion from interdependence, I follow the studies of Dungey et al. (2005, 2007) and include in my multinomial logistic model more covariates than Bae et al. (2003) did. More particularly, I include the US stock market returns (proxied by the Dow Jones Industrial [DJI] returns), the conditional volatility of the average eurozone stock market returns (proxied by the EUSTOXX50 returns) modelled as EGARCH(1,1); eurozone money market interest rate level (three-month EURIBOR); US Treasury note yield changes; and returns on the Euro-Croatian kuna (EUR-HRK) and the US dollar-Croatian kuna (USD-HRK) exchange rates. Additionally, this article examines also whether the most recent episodes of financial market distress significantly impacted the probability of contagion between the Croatian and selected stock markets of eurozone.

2. Methodology

Exceedance return in this article is defined as a negative return on a day t that is below the 5th quantile of the empirical marginal distribution of returns of a particular stock market. 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 modelled as a polytomous variable (Dajčman, 2013a). The dependent polytomous variable at time t (y_t ; $t = 1, \dots, T$) can take 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. 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 (Bae et al., 2003). The multinomial logit model assumes that the probability of observing category i (of the three possible categories) is given by Equation (1) (Greene, 2003).

$$P_j = \Pr(y_t = j) = \frac{\exp(\beta'_j x)}{\sum_{k=1}^3 \exp(\beta'_k x)}, \quad (1)$$

where 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.² In this article I chose to include the following covariates: US stock market returns proxied by returns on the DJI index; the conditional volatility of the average eurozone stock market returns, proxied by the EUROSTOXX50 returns, modelled as EGARCH(1,1); the eurozone money market interest rate level (three-month EURIBOR); 10-year US Treasury note yield level; and returns on the EUR-HRK and USD-HRK exchange rates. In order to provide the answer whether the probability of contagion increases in a crisis (as compared to a non-crisis) period, I also included two instrumental (dummy) variables.³ The first instrumental variable takes value 1 for the crisis period from September 16, 2008⁴ to 22, 2010 and 0 otherwise, while the second takes value 1 for the period from April 23, 2010 to January 27, 2012⁵ and 0 otherwise.

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 I impose normalisation (see Greene, 2003). I achieve normalisation by setting the value of the coefficient for the first category ($j = 1$) to zero. All regression coefficients of Equation (1) are thus calculated with respect to the first category (i.e. category 1) as a base category (see also Dajčman, 2013), and the relative probabilities of outcome j ($j=1$) to the base category equals:

$$P_j = \Pr(y_t = j) = \frac{\exp(\beta'_j x)}{1 + \sum_{k=2}^3 \exp(\beta'_k x)}. \quad (2)$$

The model is estimated using maximum likelihood with the log-likelihood function for a sample of t observations given by Dajčman (2013).

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

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

$$pseudoR^2 = 1 - \left(\frac{\log L_\omega}{\log L_\Omega} \right). \quad (4)$$

Once the estimates of the regression coefficients are obtained the probabilities of each of the three categories, P_j , are computed

$$P_j = \frac{\exp(\beta'_j x^*)}{1 + \sum_{k=2}^3 \exp(\beta'_k x^*)}, \quad (5)$$

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. (2003), 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).

$$\delta_j = \left. \frac{\partial P_j}{\partial x} \right|_{x=x^*} = P_j \left[\beta_j - \sum_{k=1}^3 P_k \beta_k \right] \Big|_{x=x^*}. \quad (6)$$

Econometric models were estimated by Stata software.

3. Data and empirical results

Co-exceedances in the returns of six eurozone countries, listed in Table 1, are analysed for the period from December 3, 2003 to January 27, 2012. The returns were calculated as the differences in the logarithms of the daily closing prices. The stock indices included are: the CROBEX (for Croatia), Athens Composite Index (ACI, for Greece), ATX (for Austria), BUX (for Hungary), CAC40 (for France), DAX (for Germany), FTSE100 (for the UK), FTSEMIB (for Italy), IBEX35 (for Spain), ISEQ (for Ireland), and RTS (for Russia). 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 source for stock indices is Yahoo! Finance.⁷ Table 1 presents the main descriptive statistics of the untransformed data.

The Jarque-Bera test rejects the hypothesis of normally distributed time series. I also performed unit root tests and proved that the return series cannot be characterised as unit root processes.⁸

In this article I define an extreme negative return or exceedance as the one that lies below the 5th quantile of the marginal empirical distribution of returns of an index series. In Table 2 the count numbers of exceedances and joint occurrences of extreme returns (co-exceedances) are reported. Notably, the greatest count of exceedances is for

Table 1. Descriptive statistics of stock indices returns.

	Min	Max	Mean	Std. deviation	Skewness	Kurtosis	Jarque-Bera statistics
CROBEX	-0.1459	0.1478	0.000196	0.01505	-0.3571	18.5568	1,939.18***
ACI	-0.1192	0.1113	-0.000555	0.01823	-0.0737	7.5269	1,640.34***
ATX	-0.1637	0.1304	0.000179	0.01868	-0.2891	11.4275	5,705.57***
BUX	-0.1265	0.2202	0.000382	0.01883	0.5059	16.0887	1,377.98***
CAC40	-0.0947	0.1059	-0.000026	0.01577	0.1642	10.4452	4,440.75***
DAX	-0.0743	0.108	0.000278	0.0153	0.1162	9.4645	3,345.76***
FTSE100	-0.09265	0.1079	0.000137	0.01349	0.1914	12.3669	7,027.12***
FTSEMIB	-0.0997	0.1087	-0.000284	0.01618	-0.1569	9.6681	3,563.07***
IBEX35	-0.1160	0.1348	-0.000084	0.01601	0.0099	12.0721	6,580.83***
ISEQ	-0.1396	0.09733	-0.000241	0.01726	-0.5573	9.8403	3,840.51***
RTS	-0.212	0.3227	0.000564	0.02505	0.4310	25.9852	4,230.28***

Notes: The Jarque-Bera statistics: ***indicate that the null hypothesis (of normal distribution) is rejected at a 1% significance level.

Source: Author calculation.

Table 2. Statistics of the counts of the co-exceedances of daily bond yield changes.

Count numbers	CROB- ACI	CROB- ATX	CROB- BUX	CROB- CAC40	CROB- DAX	CROB- FTSE100	CROB- FTSEMIB	CROB- IBEX35	CROB- ISEQ	CROB- RTS
Exceedances in either of the pair-wise observed stock markets	128	124	138	120	110	112	120	130	132	130
Co-exceedances	32	34	27	36	41	40	36	31	30	31

Notes: CROB = CROBEX. The number of exceedances in a particular stock market is only 95. Namely, because only the lower 5% of the extreme returns are of interest, there are $0.05 * 1918 = 95,9 = 95$ exceedances, where 1918 is the number of observations.
Source: Author calculation.

the pair of stock markets Croatia–Hungary (138) and the greatest number of counts of co-exceedances for the stock markets Croatia–Germany.

Next, the Figure 1 presents the time series of (co-)exceedances for particular pair-wise observed stock markets. As evidenced, in the period from the December 2003 until the start of 2007, there were no co-exceedances and also the frequency of exceedances was relatively low when compared to the later time periods. The first instances of co-exceedances between the Croatian and other observed European stock markets occurred in the 2007, with the subprime mortgage crisis as the predecessor of the global financial crisis. After the second half of 2008, with the start of the global financial crisis, the count of (co-)exceedances across all observed pairs of stock markets markedly increased.

Judging just from Figure 1 and not controlling for the effects of the control variables, contagion between the pair-wise observed stock markets would be identified when the counts of outcome 3 increased compared to non-crisis periods. This would clearly be during the global financial crisis and in the second half of the 2011, when the eurozone debt crisis spread to Spain and Italy. However, as argued in Section 2 of this article, to separate contagion from interdependence, we must control for the effects of the common world and regional factors. In this article this is achieved by estimating multinomial logistic model (1). Results of the model are reported in Tables 3a and 3b.

The results of the multinomial logit model (1) show that the DJI returns and conditional volatility of the EUROSTOXX50 returns are significantly different from zero for all pair-wise observed stock markets and thus have the greatest power in explaining the log odds of (co-)exceedances in the stock markets. From the data in Table 3 follows that for the stock indices CROBEX-ACI, a 1 unit (i.e. 1%) increase in the DJI returns is

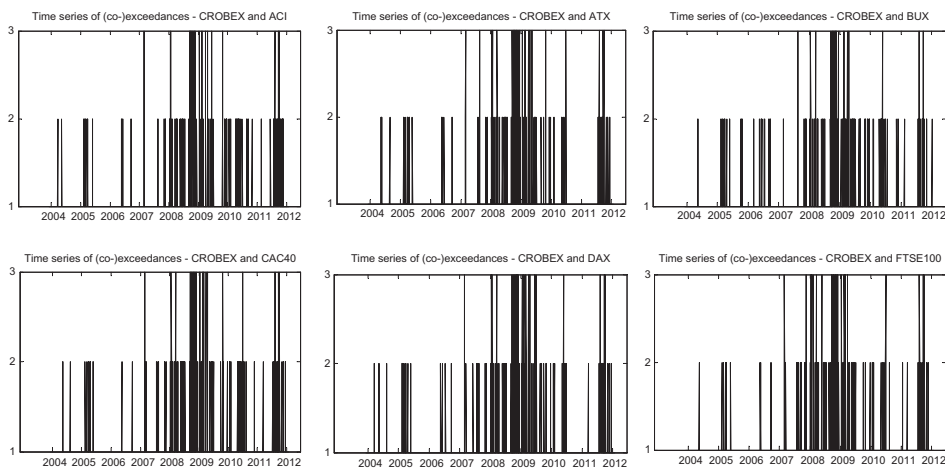


Figure 1. Time series of (co-)exceedances between Croatian and observed European stock markets.

Notes: Time series of (co-)exceedances of pair-wise observed stock markets. On the y-axis the possible outcomes of the dependent polytomous variable are given: (1) presents occurrence of category 1 (i.e. no exceedance in any of the pair-wise observed stock market); (2) occurrence of category 2 (i.e. exceedance in one of the pair-wise observed stock market); and (3) occurrence of category 3 (i.e. co-exceedance of extreme negative returns in pair-wise observed stock markets).

Source: Author calculation.

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

	CROBEX-ACI	CROBEX-ATX	CROBEX-BUX	CROBEX-CAC40	CROBEX-DAX
Outcome 2					
Constant	-2.8580***	-1.6852	-2.9212***	-3.1113***	-1.6852
DJI(returns)	-82.7630 ***	-131.5731***	-99.1577***	-130.1700***	-131.5731***
cond. volatility of EUROSTOXX50 returns	3202.2140***	3259.6220***	4524.1100***	3488.3880***	3259.6220***
EURIBOR (level)	0.0838	0.1181	-0.0685	0.1695**	0.1181
USA 10y T.N. yields level	-0.2503	-0.5594**	-0.0571	-0.2842	-0.5594**
EUR-HRK returns	-135.0786	40.6484	-81.8329	6.1199	40.64843
USD-HRK returns	35.0005*	24.0336	33.4653*	22.8747	24.0336
Crisis period 1	0.8259**	-0.0091	0.2189	0.3057	-0.0091
Crisis period 2	0.3179	-0.6776	-0.8812*	0.4139	-0.6776
Outcome 3					
Constant	-3.9429**	-2.2738	-6.9416***	-4.2186**	-2.2738
DJI(returns)	-162.9468 ***	-195.2155***	-155.5274***	-213.1068 ***	-195.2155***
cond. volatility of EUROSTOXX50 returns	4550.6050***	5655.9400***	5429.6490***	5259.2250**	5655.9400***
EURIBOR (level)	0.4082*	0.2858	0.5774**	0.3813	0.2858
USA 10y T.N. yields level	-0.9316*	-1.2662***	-0.4880	-1.0107**	-1.2661***
EUR-HRK returns	20.3515	-243.7291	125.4366	-98.2633	-243.7291
USD-HRK returns	77.6399**	62.6253*	0.0007	47.9390	62.6253*
Crisis period 1	0.2891	-0.1267	1.1244	0.5469	-0.1267
Crisis period 2	-1.0624	2.1833*	0.5791	-1.0646	-2.1833*
Log likelihood	-458.1412	-409.0449	-463.0586	-412.4597	-409.0449
LR chi (16)	344.95	415.91	345.85	425.44	415.91
Pro>chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo-R ² (McFadden)	0.2735	0.3370	0.2719	0.3403	0.3370

Notes: The table presents the regression estimates of model (1). In accordance to definition of instrumental variables above, Crisis 1 is a time dummy for the first crisis period (September 16, 2008¹¹ to April, 22, 2010) and Crisis 2 is a time dummy of the second crisis period (from April 23, 2010¹² to August 31, 2011). Outcome 1 (no (co-)exceedance) is the base category. Outcome 2 presents the results of model (2) for category 2 (i.e. exceedance in one country only), whereas outcome 3 presents the results of model (2) 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 16 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). Source: Author calculation.

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

	CROBEX-FTSE100	CROBEX-FTSEMIB	CROBEX-IBEX35	CROBEX-ISEQ	CROBEX-RTS
Outcome 2					
Constant	-4.0958***	-2.5074**	-2.6903***	-2.7747***	-1.9156***
DJI(returns)	-126.3356***	-115.3074***	-117.2866***	-116.3950***	-87.4684***
cond. volatility of EUROSTOXX50 returns	2935.1710***	3038.2540***	2719.0580***	2793.1480***	3971.7650***
EURIBOR (level)	0.3160***	0.1583	0.1973*	0.3676***	0.1393
USA 10y T.N. yields level	-0.1301	-0.4334**	-0.3736*	-0.4210**	-0.4095*
EUR-HRK returns	-43.4336	97.7653	31.4675	6.4279	-11.3541
USD-HRK returns	9.1193	28.4558	51.7764***	38.0386**	38.7183**
Crisis period 1	0.7951*	0.4112	0.5313	0.5476	-0.1729
Crisis period 2	0.4054	0.5363	0.4245	-0.2032	-1.3517**
Outcome 3					
Constant	-4.2023**	-5.1571**	-3.6460*	-5.6622***	-3.3454*
DJI(returns)	-211.1928***	-188.9289***	-217.6167***	-188.9395***	-122.2652***
cond. volatility of EUROSTOXX50 returns	4980.8550***	3899.4050***	5051.2080***	3357.2130**	3504.3630***
EURIBOR (level)	0.8186***	0.26374	0.0564	0.84164***	0.5041**
USA 10y T.N. yields level	-1.2876**	-0.6494	-0.7716	-0.9484*	1.1076**
EUR-HRK returns	-73.7206	-119.2283	-36.7704	-39.1311	21.7260
USD-HRK returns	63.0662*	70.4763**	65.7801*	18.1598	70.7346**
Crisis period 1	0.1811	1.5760	-0.3071	1.4042	1.1291
Crisis period 2	-1.3942	-0.3989	-2.2347	-1.1912	-0.4211
Log likelihood	-412.0323	-418.9020	-435.1052	-432.5631	-471.6542
LR chi (16)	413.45	412.56	393.42	400.79	320.33
Pro>chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo-R ² (McFadden)	0.3341	0.3300	0.3113	0.3166	0.2535

Note: See notes for Table 3a.

Source: Author calculation.

associated with a 0.83⁹ 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 1.63) 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 0.32 increase in relative log odds of outcome 2 and a 0.46 increase of log odds of outcome 3 versus the outcome 1. The same signs and a similar magnitude of impact on the log odds of probabilities of outcomes can be observed also for other stock indices pairs.

For some stock market pairs also the 10-year US Treasury note yield level, the USD-HRK exchange rate returns and the three-month EURIBOR level significantly impact the log odds of (co-)exceedances. I thus found that the 1 unit increase (1%) increase in the 10-year US Treasury note yields is associated with a significant (at 5% level) drop of log odds of outcome 2 (versus outcome 1) for the stock markets indices CROBEX-ATX, and CROBEX-DAX, CROBEX-FTSEMIB, and CROBEX-ISEQ. A 1 unit increase in the 10-year US Treasury note yields level is associated with a drop in the log odds of outcome 3 (versus outcome 1) for the stock indices of CROBEX-ATX, CROBEX-CAC40, CROBEX-DAX, CROBEX-FTSE100, and CROBEX-RTS. The increases in the three-month EURIBOR level are associated with an increase in the log odds of exceedance (against no (co-)exceedance) for the stock market indices pairs CROBEX-ATX, CROBEX-FTSE100, and CROBEX-ISEQ. The log odds of contagion (i.e. co-exceedance) against no exceedance or co-exceedance are significantly increased when the three-month EURIBOR level increases for the stock indices pairs CROBEX-BUX, CROBEX-FTSE100, CROBEX-ISEQ, and CROBEX-RTS.

While the EUR-HRK has no impact on the (co-)exceedances in the stock markets, the increase of the USD-HRK exchange rate (i.e. depreciation of the HRK against the USD) is associated with an increase in the log odds of (co-)exceedances for stock indices CROBEX-ACI, CROBEX-FTSEMIB, CROBEX-IBEX35, CROBEX-ISEQ, and CROBEX-RTS. Time dummy variables, included in the model (1) in order to analyse the whether the global financial crisis and the eurozone debt crisis have significantly increased the log odds of (co-)exceedances in the pair-wise observed stock markets, are significantly different from zero only for some of pair-wise observed stock indices. Notably the log odds of exceedance in one of the stock indices CROBEX-ACI (against occurrence of no exceedance in any of the stock indices) has increased in the period of the global financial crisis, but not during the eurozone debt crisis. The log odds of exceedance in one of the stock indices CROBEX-RTS reduced during the eurozone debt crisis period.

As a meaningful economic interpretation of the multinomial logit model coefficients is not always easy I follow Greene (2003) and also calculate marginal effects. The marginal effects and probabilities of outcomes are reported in Tables 4a and 4b.

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 probabilities of observing exceedance range between 0.0574 (for CROBEX-DAX) and 0.0719 (for CROBEX-DAX), while the probabilities of co-exceedance (or contagion) range between 0.0141 (for CROBEX-BUX) and 0.0214 (for CROBEX-DAX). These probabilities are calculated without controlling for covariates, though.¹⁰ As noted, to separate contagion from interdependence, it is important to control for common world 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 0.0345 (for

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

	CROBEX- ACI	CROBEX- ATX	CROBEX- BUX	CROBEX- CAC40	CROBEX- DAX
<i>Outcome 2</i>					
DJI(returns)	-3.6527***	-4.6720***	-4.6639***	-4.6797***	-4.3695**
cond. volatility of EUROSTOXX50 returns	141.4855***	160.9354***	212.9184***	125.4309***	108.2002***
EURIBOR (level)	0.0037	0.0045	-0.0033	0.0061	0.0039
USA 10y T.N. yields level	-0.0110	-0.0109	-0.0027	-0.0102	-0.0186**
EUR-HRK returns	-5.9875	-1.2867	-3.8681	0.2248	1.3684
USD-HRK returns	1.5439*	0.9155	1.5780	0.8219	0.7965
Crisis period 1	0.0467	0.0034	0.0108	0.0120	-0.0003
Crisis period 2	0.0154	-0.0193	-0.0342**	0.0167	-0.0192
<i>Outcome 3</i>					
DJI(returns)	-0.3102**	-0.3691**	-0.2273*	-0.2449**	-0.3358**
cond. volatility of EUROSTOXX50 returns	8.5813**	9.4039**	7.8566*	6.0320*	9.7635**
EURIBOR (level)	0.0008	0.0010*	0.0009*	0.0004	0.0005
USA 10y T.N. yields level	-0.0018*	-0.0016*	-0.0007	-0.0012**	-0.0022**
EUR-HRK returns	0.0519	-0.0834	0.1955	-0.1158	-0.4318
USD-HRK returns	0.1482	0.0747	-0.0025	0.0554	0.1088
Crisis period 1	0.0005	0.0024	0.0025	0.0004	-0.0002
Crisis period 2	-0.0016	-0.0005	0.0011	-0.0010	-0.0025*
<i>Probabilities 1</i>					
Outcome 1	0.9166	0.9176	0.9140	0.9187	0.9213
Outcome 2	0.0667	0.0647	0.0719	0.0626	0.0574
Outcome 3	0.0167	0.0177	0.0141	0.0188	0.0214
<i>Probabilities 2</i>					
Outcome 1	0.9516	0.9583	0.9489	0.9614	0.9637
Outcome 2	0.0465	0.0396	0.0496	0.0374	0.0345
Outcome 3	0.0020	0.0021	0.0015	0.0012	0.0018

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 (5). All estimated parameters and probabilities are rounded to the fourth decimal. ****/**/* denote the 1%, 5%, 10% significance of the rejection 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.

Source: Author calculation.

CROBEX-DAX) and 0.0496 (for CROBEX-BUX), and probabilities of outcome 3 between 0.0010 (for CROBEX-FTSE100, and CROBEX-ISEQ) and 0.0028 (for CROBEX-RTS). The probabilities for observing the 'true' contagion are thus the greatest for stock indices CROBEX-RTS.

Turning now to marginal effects of specific covariates, I find that the signs of the covariates stay the same as in Table 3. Also, the same covariates remain significant: DJI returns, EUROSTOXX50 conditional volatility, 10-year US Treasury note yield level, the USD-HRK exchange rate returns and the three-month EURIBOR level. Positive (negative) DJI returns reduce (increase) the probability of extreme negative returns in

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

	CROBEX- FTSE100	CROBEX- FTSEMIB	CROBEX- IBEX35	CRIBEX- ISEQ	CROBEX- RTS
<i>Outcome 2</i>					
DJI(returns)	-4.5129***	-4.1515***	-4.6357***	-4.7006***	-3.8175***
cond. volatility of EUROSTOXX50 returns	104.8460***	109.4566***	107.4701***	112.8511***	173.6057***
EURIBOR (level)	0.01123**	0.0057	0.0078*	0.0148***	0.0060
USA 10y T.N. yields level	-0.0046	-0.0156**	-0.0148*	-0.0170**	-0.0178*
EUR-HRK returns	-1.5515	3.5374	1.2496	0.2617	-0.5003
USD-HRK returns	0.3240	1.0230	2.0483***	1.5380**	1.6877**
Crisis period 1	0.0362	0.0165	0.0247	0.0259	-0.0074
Crisis period 2	0.0162	0.0224	0.0189	-0.0078	0.0446***
<i>Outcome 3</i>					
DJI(returns)	-0.2084*	-0.3076**	-0.3167**	-0.1834*	-0.3265**
cond. volatility of EUROSTOXX50 returns	4.9172*	6.3073*	7.3494**	3.2287	9.1730**
EURIBOR (level)	0.0008*	0.0004	0.0001	0.0008*	0.0014**
USA 10y T.N. yields level	-0.0013**	-0.0011	-0.0011	-0.0009*	-0.0030**
EUR-HRK returns	-0.0728	-0.2048	-0.0567	-0.0393	0.0614
USD-HRK returns	0.0633	0.1157	0.0947	0.0165	0.1904*
Crisis period 1	0.0002	0.0046	-0.0004	0.0023	0.0047
Crisis period 2	-0.0010	-0.0006	-0.0022*	-0.0009	-0.0009
<i>Probabilities 1</i>					
Outcome 1	0.9208	0.9187	0.9161	0.9155	0.9161
Outcome 2	0.0584	0.0626	0.0678	0.0688	0.0678
Outcome 3	0.0209	0.0188	0.0161	0.0156	0.0162
<i>Probabilities 2</i>					
Outcome 1	0.9618	0.9608	0.9572	0.9568	0.9513
Outcome 2	0.0372	0.0375	0.0413	0.0422	0.0459
Outcome 3	0.0010	0.0017	0.0015	0.0010	0.0028

Note: See notes for Table 4a.

Source: Author calculation.

investigated eurozone stock markets and increased conditional volatility of EUROSTOXX50 returns increases the probability of extreme negative returns in the observed stock markets. Increases in 10-year US Treasury note yield level are associated with lower probability of extreme negative returns in the observed stock markets, while depreciation of HRK against USD and a higher level of three-month EURIBOR with a higher probability of extreme negative returns in stock markets.

The responsiveness of the co-exceedance variable to shocks in the US stock markets is significant for all multinomial logit models of pair-wise observed stock markets. It is interesting to note, that the one unit decrease in US returns increases more the probability of exceedance than the probability co-exceedance thus indicating that some of the pair-wise observed stock markets react more intensely to the shocks in the US stock market than the other pairs of stock markets do. For the CROBEX-ACI indices the estimated marginal coefficient for the US returns shows that a 1% fall in DJI index increases the probability of exceedance in ACI or ISEQ returns by 3.65%, while the

probability of co-exceedance is increased by only 0.31%. It is also interesting to note that an increase in the EUROSTOXX50 conditional volatility increases more the probability of exceedance than the probability of co-exceedance.

To answer whether the global financial crisis and the eurozone debt crisis significantly influenced the probability of contagion in the markets, one needs to examine the time dummy variables. As evident from Tables 4a and 4b, the marginal effects of time dummies are significantly different from zero only for indices pairs CROBEX-ACI and CROBEX-RTS. The probability of exceedance in one of the stock indices in the pair CROBEX-ACI (against occurrence of no exceedance in any of the stock indices returns) has increased in the period of the global financial crisis. The probability of exceedance in one of the stock indices CROBEX-RTS reduced during the eurozone debt crisis period.

The findings of the article have implications for the investors in the Croatian stock market as well as for economic policy, especially monetary policy. It has been recognised in the mainstream financial economics (dating back to Markowitz 1958 and Grubel 1968) that increased co-movement observed during financial market contagion reduces benefits of international financial portfolio diversification. The finding that contagion from developed to Croatian stock market occurs during international financial market turbulence contagion analysis is also important for financial market supervisory authorities because of their implications for the stability of financial markets policy (Clare and Lekkos, 2000; Berben and Jansen, 2005; Dajčman 2013). The threat of contagion calls for a swift policy reaction in order to reassure financial market participants and prevent shock-spillovers between financial market segments and to nonfinancial segments of the economy. The negative consequences of the global financial crisis have stressed the importance of the financial market surveillance, identification of systematic financial market shocks and contagion. The methodology applied in this article enabled me to separate increased interdependence from contagion. I have shown that increased probability of exceedances of the Croatian and developed European stock markets during the recent global financial crisis and eurozone debt crisis were not a result of contagion from the later to the Croatian stock market.

4. Conclusion

In this article I examined pair-wise contagion between the Croatian and 10 European stock markets during the period from December 3, 2003 to January 27, 2012. Contagion was defined as an occurrence of large negative returns (i.e. co-exceedances) jointly in two stock markets and a multinomial logit was applied to control for common world and regional factors that affected all stock markets simultaneously.

I found that the DJI returns, EUROSTOXX50 conditional volatility, 10-year US Treasury note yields level, the USD-HRK exchange rate returns and the three-month EURIBOR level impacted significantly impacted the probability of (co-)exceedance in the pair-wise observed stock markets. Positive DJI returns reduced the probability of extreme negative returns in investigated eurozone stock markets and increased conditional volatility of EUROSTOXX50 returns increases the probability of extreme negative returns in the observed stock markets. Increases in 10-year US Treasury note yield level were found to be associated with lower probability of extreme negative returns in the observed stock markets, while depreciation of HRK against USD and a higher level of three-month EURIBOR with a higher probability of extreme negative returns in stock markets.

The applied econometric technique enabled us to separate contagion from interdependence. I found that the probability of contagion between the Croatian and observed European stock markets did not significantly increase during the global financial crisis and the eurozone debt crisis.

Notes

1. There is no common definition of contagion. For a review of definitions see for example, Forbes and Rigobon, 2001; Dornbusch et al., 2001; Corsetti et al., 2001; Pericoli and Sbracia, 2003; Baur and Lucey, 2009.
2. To separate contagion from interdependence, it is important to identify world and regional factors that impact all countries simultaneously (Dungey et al., 2005).
3. 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. The DJI returns, US Treasury note yields and the USD-HRK 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 eurozone money market rate, the conditional volatility of the average eurozone stock market returns and the HRK-EUR returns are included as region-specific factors that capture regional financial market conditions. 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. I take this date as the start of the sovereign debt crisis in the eurozone.
6. The same approach is used by Forbes and Rigobon (2002).
7. The data series for the CROBEX were obtained from the web page of the Zagreb Stock Exchange, for the EUR-HRK, and USD-HRK exchange rates from the web page of central bank of Croatia (Hrvatska narodna banka), and for the three-month EURIBOR the web page of Deutsche Bundesbank. The data series of EUROSTOXX50 and the 10-year US Treasury note yields are from Yahoo! Finance.
8. The results are not presented here, but can be obtained from the author.
9. $0.01 * (-82.76) = -0.83$, as in the data a 1% is expressed as 0.01.
10. If outcomes were independent, then the probabilities of co-exceedances between all pair-wise observed stock indices would be $0.05^2 = 0.0025$.
11. On September 16, 2008, the investment bank Lehman Brothers collapsed and started the global financial crisis.
12. On April 23, the Greek government requested a bailout from the EU/IMF. I take this date as the start of the sovereign debt crisis in Eurozone.

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