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Contagion from the crises in the Euro-zone: where, when and why?

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ABSTRACT
The prevalence of contagion between the Euro-zone countries and other European countries since the Greek crisis of 2009 is now well – known, but the factors that influence the pattern of this contagion are not well understood. We investigate this question both within Europe and beyond to the USA and Japan, using an asymmetric M-GARCH model that focuses on extreme values of the risk premia on government bonds. We compare these extreme values with news of major events and find that they are highly correlated. We find a different pattern of contagion emanating from Ireland compared to the other crisis countries of Greece, Italy, Portugal and Spain. We also examine the factors that have made countries vulnerable to contagion and find that financial factors are more important than trade ones. However, intra-Euro-zone trade has also been a significant factor between the major Euro-zone economies. There is little evidence that global factors affect contagion between EU member states, but some evidence that nominal exchange rate movements offer a degree of insulation from contagion for the non-Euro zone states.

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1. Introduction

The phenomenon of financial market contagion, whereby a crisis in one country may spread to affect others, has attracted attention in the context of a series of crises that have occurred since the early 1990s. Particularly noteworthy have been the East Asian financial crisis in 1997/98, where the crisis in Thailand spilled over and affected many regional neighbours, as well as reaching both Russia and Argentina, and the Euro crisis that erupted in 2009. While the literature has sometimes sought to distinguish between various types of contagion including wake-up call contagion, shift contagion and pure contagion unrelated to fundamentals, mixed findings have been reported relating to both the pattern and extent of contagion.[1]

In the context of the Euro-zone crisis many studies have adopted conventional correlation techniques as a way of identifying contagion and have used continuous high frequency data to focus on the co-movement in government bond yields. The results have again been mixed and are not directly comparable because of differences in the details of the estimation techniques used and countries and time periods covered. For example, while not offering any tests of statistical significance, Missio and Watzka (2011), present evidence to suggest the risk premia in Portugal, Spain, Italy and Belgium have been correlated with those in Greece. Muratori (2014) also discovers similar evidence of contagion. In contrast, using a time varying spillover regime switching model and a time varying conditional copula model, Philippas and Siriopoulos (2013) find no significant contagion effect from Greece on Portugal, Italy and Spain. Meanwhile, Pragidis et al. (2015) find that in many cases the correlation between bond yields in Greece and elsewhere actually decreased after the eruption of the Greek crisis in 2009. Statistical correlation techniques for examining contagion, have included dynamic conditional correlation

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(Chiang, Jeon, and Li 2007; Engle 2002), asymmetric generalized conditional correlations (Cappiello, Engle, and Sheppard 2006), and copula functions (Jondeau and Rockinger 2006; Kenourgios, Samitas, and Paltalidis 2011).

An often preferred method of measuring contagion is based on selecting extreme negative events and examining their effects, rather than using all observations which combine small and large changes in the risk premium. In the modern literature on contagion, the extreme negative events have usually been located in the Euro-zone or more specifically in Greece. Using this approach, Forbes (2012), for example, discovers that contagion between stock markets is stronger in the Euro-zone than in her full sample of countries. Using a similar approach, Aizenman et al. (2012) examine the impact of the Euro-zone crisis on developing countries, while Stracca (2015) investigates the effects of the crisis in 2010–12 on a wide range of both advanced OECD countries and non-OECD emerging and developing economies. He discovers that the crisis contributed to a rise in global risk aversion and a fall in equity returns, mainly in the financial sector, with the impact on government bond yields being much more muted.

In this paper we also adopt an approach based on extreme negative events in terms of government bond yields, but we confirm our identification of extreme events by testing the correlation between the extreme values of bond yields and 'news' events reported in the media that we assess as being particularly negative. We find them to be highly correlated. In addition we make three contributions to the existing literature. First, many of the published studies have been relatively narrow in their span and scope, often because they were undertaken while the crisis was still in progress. In contrast, we examine the geographical extent of contagion between eight Euro-zone member states, a further six European states as well as the USA and Japan. Although all are advanced economies, they have varying degrees of capital market integration and very different exchange rate regimes, which may have a bearing on the direction and extent of contagion from the EU Crisis countries; Portugal, Ireland, Italy, Greece and Spain (PIIGS). By using a system estimation technique we are also able to consider the potentially difficult issue of reverse or two-way causality between the PIIGS.

Second, given the duration of the Euro-zone crisis we are able to examine the time-varying pattern of contagion. We look at different sub-periods, when the crisis has possessed different degrees of intensity, and use dynamic conditional correlations (see, for example, Aielli 2013) at both daily and weekly frequencies to examine the time-varying nature of contagion.

Third, observing that some countries are subject to greater contagion than others leads to the question of why this is. We therefore estimate empirically what factors affect vulnerability to contagion from an extreme negative event elsewhere. Whilst acknowledging the possible links between them, Forbes (2012) emphasizes the importance of trade, banks, portfolio investment and wake up calls. She finds evidence to suggest that, while all these channels have been significant, wake up calls have been the least important and leverage in the domestic banking sector has been the most important. In a related exercise based on the Euro crisis in 2010–12, Stracca (2015) finds that the strength and direction of contagion depend on trade exposure to the Euro area, EU membership and whether the country's exchange rate is pegged to the euro. In this paper we examine the importance of trade intensity with the Euro-zone, the structure of the financial and banking sectors, the amount of fiscal space, and indicators of macroeconomic fundamentals. One main objective is to discern whether contagion occurs primarily through the financial or real sector of the economy.

The paper is structured as follows. Section 2 outlines the methodology and the model used to test for contagion. As noted earlier, our main methodological approach uses extreme event analysis but we also supplement this by examining alternative approaches using GARCH and conditional probit models. Section 3 explains the data set used and Section 4 reports the results from the multivariate eGARCH model. Section 5 uses a conditional logistic model to examine the underlying macroeconomic factors that explain vulnerability to contagion. Section 6 offers a few concluding remarks and briefly explores the implications of our findings for policy.

2. The model and methodology

The contagion we explore is that emanating from Euro-zone long-bond government markets, linked directly to the debt crisis faced by many Euro-zone economies after 2008, but most especially Portugal, Ireland, Italy, Greece and Spain. To this end we focus on the sovereign risk premium, ρ_i, defined as the difference between the 10-year bond yield of country i less the German ($\bar{r}$) long-term bond yield measured in Euros, that is: $\rho_{it} = r_{it} - \bar{r}_t$.

Since asset returns are likely to exhibit volatility clustering, whereby the current level of volatility is positively related to its level in the immediately preceding periods, we model this using the M-GARCH class of models that can be written as

$$\rho_{it} = \beta_{0i} + \varepsilon_{it} \ \textit{where}\ \varepsilon_{it} \sim N(0, H_t) \tag{1}$$

and where ρ_{it} is a $n \times 1$ vector of risk premia, β_{0i} is a corresponding $n \times 1$ vector of constants and the error term, ε_{it}, has a zero mean but time-varying variance, denoted by the variance-covariance matrix, H_t which is of dimension $n \times n$.

This basic specification, however, does not allow us to identify any specific cause of contagion. As contagion is something which goes beyond a normal level of interdependence, if we assume that β_{0i} denotes the average level of interdependence between the set of risk premia, then contagion must be additional to this.[2] In the Euro-zone crisis we know that crises manifested themselves first in Greece, but then Ireland, Italy, Portugal and Spain became additional, although not necessarily wholly independent, sources of risk, and hence potential sources of contagion at different times over the sample. To capture these additional potential sources of contagion we include the extreme values of the measured risk premium from each of the crisis countries, ρ_{jt}^{exv}, as additional explanatory variables to (1), to give:

$$\rho_{it} = \beta_{0i} + \sum_{j=1}^{5} \beta_j \rho_{jt}^{exv} + \varepsilon_{it} \tag{2}$$

where the subscript j denotes the five crisis countries, and ρ_{jt}^{exv} denotes the extreme values of the measured risk premium in each of the five crisis countries as measured by observations one standard deviation above the mean. At this stage we assume that the elements of ρ_{jt}^{exv} are independent, although interactive terms can be included in the model. The coefficients $\beta_j = (\beta_{GR,}\beta_{IR,}\beta_{IT,}\beta_{PO,}\beta_{SP})$ measure the impact of a rise in the relevant risks in each of the crisis countries to a wider set of i-country risk premia, where $i > j$ and $j \subset i$.

The sign of β_j is ambiguous. In the case of direct contagion β_j is expected to be positive as the additional risk spreads to other countries whose bonds are perceived as having similar risk characteristics to those of country *j*, and whose currencies are closely linked to the value of the euro. But the sign of β_j can also be negative if the country concerned (here referred to as the 'home' country) is deemed to be a safe haven. In this case, investors flee euro-denominated assets and purchase home country bonds. If this capital flow is sufficiently large it will raise the price of home countries' bonds and lower their yield, relative to those of German bonds, thus reducing the interest rate differential.[3] Unless Germany's interest rates for some reason fall by more, this will reduce the interest differential. In such cases the implication is that, in search of greater safety, more funds would be diverted to countries outside of the Euro-zone than to Germany itself.

In order to estimate the model we need to allow for the stylized fact that the basic GARCH model is symmetric and so therefore does not capture the observed asymmetry in financial returns data. Asymmetry implies that unexpected bad news (such as an increase in the risk premium) increases conditional volatility more than unexpected good news (such as decrease in risk premium), of similar magnitude. To capture this asymmetry there are a number of alternative GARCH models including, eGARCH (Nelson 1991), GJR-GARCH (Glosten, Jagannathan, and Runkle 1993), APARCH (Ding, Granger, and Engle 1993), AGARCH, (Engle and Ng 1993), TARCH (Zakoian 1994) and NAGARCH (Higgins and Bera 1992). In this paper we follow a multivariate asymmetric GARCH approach, selecting the model which gives the best fit to the data, which is usually the eGARCH model, where the multivariate conditional variance is specified as:

$$\ln h_{it} = c_i + b_i \ln h_{it-1} + a_i f(z_{it-1}) \tag{3}$$

where $f(z_{i,t-1}) = (|z_{i,t-1}| - E(|z_{i,t-1}|) + \gamma_i z_{i,t-1})$ and where $z_{i,t} = \varepsilon_{it}/h_{i,t}^{-1/2}$, is the standardised error. Equation (3) shows that the variance depends on a constant, c_i; the persistence of country-specific volatility, as measured by b_i; and on a series of 'news terms" captured by the parameters, a_i. This says that the conditonal heteroscadasticity is an asymmetic function of past standardised innovations, $z_{i,t-1}$. The term $(|z_{i,t-1}| - E(|z_{i,t-1}|))$ measures the magnitude of past innovations, which is positive if $\gamma_i = 0$ and the size of $z_{i,t-1}$ is greater than its expected value. The term γ_i captures what is known as the leverage effect and it measures the sign of the effect of past innovations. If $\gamma_i > 0$ then h_{it} is rising by more than when $\gamma_i = 0$ and by less if $\gamma_i < 0$. Thus if $\gamma_i > 0$ then bad news (a rise in risk) leads to a greater rise in the conditional volatility, but if $\gamma_i < 0$ then good news (a fall in a country's risk premia) means the conditional volatility rises by less than in the symmetric case.

Under the conditional normality assumption the log-likelihood function $L(\Theta)$, for the multivariate eGARCH model is written as:

$$L(\Theta) = \left[-\frac{1}{2}(kn)(\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{n}(\ln|H_t| + \varepsilon'_t H_t^{-1}\varepsilon_t) \right] \tag{4}$$

where Θ is the parameter vector to be estimated, k is the number of equations, n is the number of observations, ε'_t is the vector of innovations at time t and H_t is the time – varying conditional variance – covariance matrix with diagonal elements given by equation (3).

As a robustness check on the results we also make use of the quantile method, (see Koenker and Hallock 2001) where the conditional median function for the risk premium, $Q_q(\rho|X)$, given $q \in (0, 1)$ splits the sample data into proportions q below and (1 – q) above the median. The quantile regression method then gives asymmetric penalties $(1 - q)|e_i|$ for over-prediction and $q|e_i|$ for under-prediction where $|e_i|$ is the series for the absolute residual. The quantile regression estimator minimizes the objective function:

$$Q(\beta_q) = \sum_{i:\rho_i \geq X'_q\beta}^{n} q|\rho_i - X'_j\beta_q| + \sum_{i:\rho_i \leq X'_q\beta}^{n} (1-q)|\rho_i - X'_j\beta_q| \tag{5}$$

where Q is the number of partitions of the data set, in this case 4, for quartiles, X_j is the n x 5 matrix of extreme values of the risk premium, where $j \subset i$, and β_q the coefficient estimates. The quantile regression estimator is asymptotically normally distributed and estimated using linear programming methods.

3. The data

Matching average daily 10-year sovereign bond yields were taken from investing.com and average daily spot exchange rate data from the ECB website for 18 countries from 1st October 2009 until 12th August 2016[4] which, allowing for weekends and bank holidays, gives 1,746 observations. There are the five crisis countries; Portugal, Ireland, Italy, Greece and Spain, plus four other Euro-zone countries Belgium, France, Germany and the Netherlands. There are three central and eastern European countries which have effectively a pegged rate with the Euro – The Czech Republic, Hungary and Poland – and then five other non-Euro countries – three in Europe – Sweden, Switzerland and the UK and two other's Japan and the USA. Since we are not strictly testing for market efficiency the trading time differences between the European markets hours is not crucial, as we are using average daily data, although we do not include the USA and Japan in the daily analysis, but only in the weekly analysis, which is used to see if there is a different pattern of contagion over a slightly longer time horizon.

The interest rate differential (or risk premium) for Euro-zone members is the difference between the home country bond yield and the German yield. For consistency, all country risk premia are computed with reference to the German long-bond yield, as the contagion we wish to measure refers to the Euro-zone. For countries that are not members of the Euro-zone, an alternative measure was calculated allowing for expected changes in the spot exchange rate. The 'home' interest differential for these countries is defined as $\rho_{it} = (r_{it} - x_{it}) - \bar{r}_t$ where r_{it} is the long-term sovereign bond yield of the home country i in period t in its domestic currency and x_{it} is the expected bilateral depreciation of the home currency against the euro.[5]

To compute the extreme events for Portugal, Ireland, Italy, Greece and Spain, we defined extreme values of the risk premium as values that were greater than one standard deviation from the mean.[6] The ρ_{jt}^{exv} series were computed by the formula: $\rho_{jt}^{exv} = \rho_{jt} \times DUM_j$ where DUM_j is a country-specific (0, 1) dummy which takes the value of unity when the country risk premium exceeds one standard deviation of its mean and zero otherwise. The ρ_{jt}^{exv} series were then compared to actual news events (see Bird, Du, and Willett 2017b) over the core period of the sample. There are about eighty identified important news events (see Table 5 of the online Appendix for

Table 1. Correlations between the extreme values news events and crises countries.

Correlations between the extreme values news events [20 Oct 2009–30 Apr 2014].		
	Important News	*No. of events*
EXVGR	0.99***	*374*
EXVIR	0.99***	*373*
EXVPO	0.99***	*444*
EXVSP	0.99***	*447*
EXVIT	0.99***	*453*
No. of events	*80*	

Correlation between PIIGS news events					
	EXVGR	EXVIR	EXVPO	EXVSP	EXVIT
EXVGR	1	0.25	0.83	0.63	0.84
EXVIR		1	0.39	0.03	0.20
EXVPO			1	0.57	0.78
EXVSP				1	0.78
EXVIT					1

Notes: *** indicates the significant level of 1%. where EXV refers to the extreme value of the interest rate differential and the country identifiers are GE = Greece, IR = Ireland, PO = Portugal, SP = Spain, and IT = Italy

details) that are likely to affect all the crisis countries, and which had an extremely close positive association with our extreme values of the risk premia. Table 1 shows the results of a simple correlation exercise in which the correlation coefficients between the actual events and the ρ_{jt}^{exv} series for each of the five crisis countries were all equal to 0.99 and highly significant. Thus the ρ_{jt}^{exv} series provide very good proxies for news events and the potential source for contagion.[7]

As Table 1 also shows, however, the extreme values of the interest differential (or news) in each of the five crisis countries are not independent, raising the issue of potential multicollinearity if the extreme values of all five countries are included in the regression. The extreme values of the interest differential in Greece are highly correlated with the corresponding extreme values of the interest rate differentials in Italy, Portugal and Spain. Given this high degree of collinearity, from a statistical point of view, it is not unreasonable to use extreme events in Greece as representative of extreme events in all four of the crisis countries, other than Ireland.

Ireland, however, has a different profile from the other crisis countries reflecting the different nature and timing of the crisis there. Whereas the Greek crisis was essentially a public debt one, in Ireland the crisis originated in the private sector, and was reflected in a housing boom. This morphed into a fiscal crisis, however, when the government undertook a substantial bailout. Chart 1 shows the Greek and Irish daily interest rates over the whole sample. Interest rates in Ireland exceeded 6% between 7th September 2010 and 4th September 2012, a period of almost exactly two years corresponding closely with the period of the Irish crisis. Over the same period, interest rates in Greece varied from 11.8% to 21.87%. Thus, during the period of the crisis in Ireland, the risk premium in Greece was more than three times higher, although the peak of the Irish crisis, 12th July 2011, preceded that of the first Greek crisis, on 8th March 2012, by about eight months. The crisis in Ireland appears to have been less pronounced and shorter lived than the crisis in Greece. We therefore include Ireland as a potentially separate source of contagion from Greece in some of the estimated regression models and a potential source of contagion to Greece.

4. The M-eGARCH and quantile regression results

The model is estimated with data of both daily and weekly frequencies, but also with static and perfect foresight exchange rate expectations for the non-Euro area economies, using both asymmetric M-GARCH and quantile regression methods as a check on the robustness of the results. Tables 2 and 3 provide detailed results for the static exchange rate expectations case, with the very similar perfect foresight results reported in Tables 6A and 6B in the online Appendix.

Table 2. Estimation results from the aDCC – M-eGARCH model (with Static Exchange Rate Expectations).

	Mean relation					Variance model				
	β_0	β_{GR}	β_{IR}	β_{PO}	β_{SP}	β_{IT}	b	a	c	γ
Greece	7.99***		1.09**	5.07***	1.43**	0.34	0.75***	0.24***	0.05***	
	(0.44)		(0.48)	(0.32)	(0.61)	(0.30)	(0.09)	(0.09)	(0.02)	
Ireland	0.65***	0.04		0.04	−0.01	0.74***	0.91***	0.08**	0.002***	
	(0.01)	(0.03)		(0.08)	(0.02)	(0.10)	(0.04)	(0.04)	(0.0005)	
Portugal	2.19***	0.21	2.10***		1.02***	0.55	***	0.31**	0.01	
	(0.04)	(0.45)	(0.07)		(0.26)	(0.46)	0.68(0	(0.12)	(0.01)	
Spain	1.36***	0.02	0.76***	0.54***		0.34	−0.0002	0.95***	−0.19***	1.00***
	(0.01)	(0.24)	(0.07)	(0.19)		(0.36)	(0.02)	(0.01)	(0.04)	(0.24)
Italy	1.38***	0.39***	0.26***	1.12***	0.25***		0.03	0.93***	−	1.15***
	(0.01)	(0.02)	(0.004)	(0.02)	(0.10)		(0.02)	(0.02)	0.25***	(0.17)
France	0.35***	−0.47***	0.02***	0.11***	0.29***	0.01***	0.03	0.95***	(0.05)	0.85***
	(0.003)	(0.01)	(0.003)	(0.004)	(0.01)	(0.004)	(0.02)	(0.01)	−0.28***(0	(0.06)
Netherlands	0.21***	−0.001	0.07***	0.01	−0.01	0.06***	0.01	0.88***	−0.78***	1.20***
	(0.004)	(0.03)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.13)	(0.10)
Belgium	2.42***	0.22***	0.80***	0.94***	0.07***	−0.04***	−0.04*	0.93***	−0.23***	1.22***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.002)	(0.004)	(0.02)	(0.01)	(0.03)	(0.11)
Poland	2.26***	0.63***	0.84***	−0.09***	0.13***	0.13***	0.05**	0.88***	−−0.44***	1.09***
	(0.01)	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.03)	(0.10)	(0.15)
Czech Republic	0.31***	0.33***	0.46***	0.06**	0.20***	0.10**	0.05*	0.89***	−0.44***	1.04***
	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)	(0.05)	(0.02)	(0.02)	(0.09)	(0.25)
Hungary	3.23***	0.48***	1.10***	0.30***	0.04***	0.53***	0.09**	0.90***	−0.27***	1.15***
	(0.01)	(0.01)	(0.03)	(0.01)	(0.01)	(0.01)	(0.04)	(0.02)	(0.06)	(0.13)
Switzerland	−0.64***	−0.18***	−0.56***	−0.10***	−0.26***	−0.04******	0.03**	0.93***	−0.34***	0.96***
	(0.003)	(0.02)	(0.01)	(0.005)	(0.01)	(0.01)	(0.01)	(0.01)	(0.07)	(0.12)
U.K.	1.19***	0.21***	−0.62***	−0.27***	−0.68***	−0.06***	0.01	0.93***	−0.27***	0.78***
	(0.03)	(0.02)	(0.03)	(0.01)	(0.03)	(0.01)	(0.01)	(0.01)	(0.05)	(0.07)
Sweden	0.37***	−0.14***	−0.19***	−0.23***	0.01	0.02***	0.01	0.85***	−0.72***	1.32***
	(0.01)	(0.005)	(0.01)	(0.01)	(0.02)	(0.001)	(0.02)	(0.02)	(0.10)	(0.16)

Note: Estimation Results from the aDCC-M-eGARCH-TGARCH and the aDCC-M-eGARCH-NAGARCH models are the same as these; and ***, ** and * indicate the significant levels of 1%, 5% and 10% respectively.

Diagnostics: LL $= 18241.26$, $\lambda_1 = 0.39$ (0.02), $\lambda_2 = 0.58$ (0.02) and $\lambda_3 = 0.01$ (0.002), AIC $= -20.61$, BIC $= -19.84$, H-Q $= -20.33$

Risk premium equations: $\rho_{it} = \beta_0 + \beta_{GR}D_{GR} + \beta_{IR}D_{IR} + \beta_{PO}D_{PO} + \beta_{SP}D_{SP} + \beta_{IT}D_{IT} + \varepsilon_{it}$ where i = Greece, Ireland, Portugal, Spain, Italy, France, Netherlands, Belgium, Switzerland, U.K., Sweden, Poland, Czech Republic and Hungary, j = Greece, Ireland, Portugal, Spain, Italy and $\varepsilon_{it}|I_{t-1} \sim N(0, H_t)$. Variance equations $(h_{it}) = c_i + b_i ln(h_{it-1}) + \sum_{j=1}^{5} a_{ij} f_j(z_{jt-1})$.

Tables 2A and 2B show the daily frequency results for the M-eGARCH and quantile regression models respectively, for all 14 European countries with constant exchange rate expectations. The first column in both Tables 2 and 3 shows the ‘average” risk premium of the home country over Germany; in almost every case it is positive and significant. The relatively low values of β_0 for France and Netherlands reflect a very close alignment with Germany, whereas the high value for Greece shows a higher equilibrium interest rate differential with Germany. The single exception is Switzerland which has a negative sign, indicating that on average Swiss long-term interest rates on bonds were lower than in Germany.

The first finding from the regression analysis is the interdependence between the five crisis countries, as shown by the predominantly positive and significant β_1 coefficients in the top five rows of Tables 2A and 2B. In other words there is positive two-way contagion between Greece and Italy, Greece and Portugal, Italy and Portugal and Italy and Spain. This most likely reflects the common very high average debt to GDP ratios over the sample – Greece (155%), Portugal (110.9%) and Italy (127%) – as well as location juxtaposition in southern Europe. On the other hand, there are also important independencies: the risk premiums of Spain and Ireland and of Greece and Spain show no significant dependency in Table 3, although from Table 2 it seems that Ireland may export contagion to Spain and Spain to Greece. It is also the case that Ireland may spread contagion to Greece, but not vice-versa and in the quantile results Ireland may even be a safe haven for Greece.[8]

Secondly, of the three core Euro-zone economies the Netherlands is more immune from contagion from all other countries than either Belgium or France. This reflects the close relationship between the Netherlands

Table 3. Estimation Results from the Quantile Model (with Static Exchange Rate Expectations).

							Diagnostics		
	β_0	β_{GR}	β_{IR}	β_{PO}	β_{SP}	β_{IT}	0.25 Pseudo R-square	0.50 Pseudo R-square	0.75 Pseudo R-square
Greece	8.97***		3.69***	7.08***	0.53	7.64***			0.50
	(0.12)		(0.30)	(0.50)	(0.29)	(0.60)			
Ireland	2.67***	−2.24***		5.12***	0.10	0.61***			0.26
	(0.09)	(0.30)		(0.31)	(0.09)	(0.07)			
Portugal	3.94***	1.95***	3.01***		0.82***	1.97***			0.46
	(0.13)	(0.27)	(0.29)		(0.15)	(0.14)			
Spain	2.33***	−0.02	−0.02	0.58***		1.85***			0.28
	(0.05)	(0.07)	(0.07)	(0.05)		(0.07)			
Italy	1.87***	0.65***	0.02	1.02***	1.23***				0.41
	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)				
France	0.48***	0.33***	−0.01	0.22***	0.14***	0.09***			0.40
	(0.01)	(0.03)	(0.01)	(0.03)	(0.01)	(0.02)			
Netherlands	0.20***	0.003	0.07***	0.08***	0.01	0.04***		0.20	
	(0.003)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)			
Belgium	2.56***	0.91***	1.62***	0.17	−0.06	0.07			0.36
	(0.03)	(0.20)	(0.05)	(0.09)	(0.03)	(0.19)			
Poland	2.80***	0.37***	0.37***	0.32***	−0.08**	0.21***			0.38
	(0.02)	(0.04)	(0.03)	(0.04)	(0.04)	(0.04)			
Czech	0.36***	0.39***	0.48***	0.14***	0.11***	0.12***		0.39	
Republic	(0.01)	(0.06)	(0.03)	(0.04)	(0.02)	(0.03)			
Hungary	4.38***	0.67***	0.56***	0.43***	0.42***	0.74***			0.39
	(0.05)	(0.10)	(0.12)	(0.12)	(0.07)	(0.12)			
Switzerland	−0.83***	−0.14***	−0.38***	−0.09***	−0.11***	−0.04	0.25		
	(0.01)	(0.05)	(0.02)	(0.03)	(0.02)	(0.02)			
U.K.	1.11***	0.21***	−0.56***	−0.20***	−0.55***	−0.07		0.37	
	(0.01)	(0.05)	(0.02)	(0.02)	(0.03)	(0.05)			
Sweden	0.53***	−0.04	−0.18***	−0.34***	−0.05**	0.004			0.35
	(0.01)	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)			

Note: *** and ** indicate the significant levels of 1% and 5% respectively.
Number of observations = 1746
$\rho_{it} = \beta_0 + \beta_{GR}D_{GR} + \beta_{IR}D_{IR} + \beta_{PO}D_{PO} + \beta_{SP}D_{SP} + \beta_{IT}D_{IT} + \varepsilon_{it}$ where i = Greece, Ireland, Portugal, Spain, Italy, France, Netherlands, Belgium, Switzerland, U.K., Sweden, Poland, Czech Republic and Hungary

and Germany and the correspondingly low debt ratio (62%), compared to both France (86.1%) and Belgium (101.8%). Even so the Netherlands does seem to import some contagion from Ireland and Italy, and perhaps Portugal, but in every case the β_1 coefficient is very small and never larger than 0.07.

Without exception the three central and eastern European countries (CEECs) have all been subject to rising risk premiums as a result of high premia in the five crisis countries, although they are relatively small economies, which are outside of the Euro-zone, and so not as financially integrated as the members. In most cases the β_1 coefficient for Hungary is larger than those for Poland and the Czech Republic, again possibility reflecting its higher average debt ratio, which at 76.6% is more similar to that of Spain than to Poland (51.5%) or the Czech Republic (38%). Finally, Tables 2 and 3 show that the final three countries – Sweden, Switzerland and the UK – have predominantly negative β_1 coefficients so they face a fall in their risk premiums when the risk premia of the PIIGS rises. They therefore in general exhibit safe haven properties, although there is some evidence from the daily data that the UK imported contagion from Greece, from the quantile results. This is difficult to explain, although in the M-eGARCH results this positive β_1 coefficient is statistically insignificant, suggesting that this effect is not very important.

An advantage of the M-eGARCH model is that dynamic, conditional correlations are produced which illustrate the daily dynamics in the risk premium. In addition the variance model in Table 2 shows the importance of the leverage effect, characteristic of eGARCH models. With just three exceptions – Greece, Ireland and Portugal – the leverage parameter γ is highly significant and positive; suggesting that bad news (a rise in risk) leads to a greater rise in the conditional volatility in the risk premium, than when there is good news. In the case of Greece, Portugal and Ireland (in the daily data only) the persistence effects dominate the asymmetric news effects with

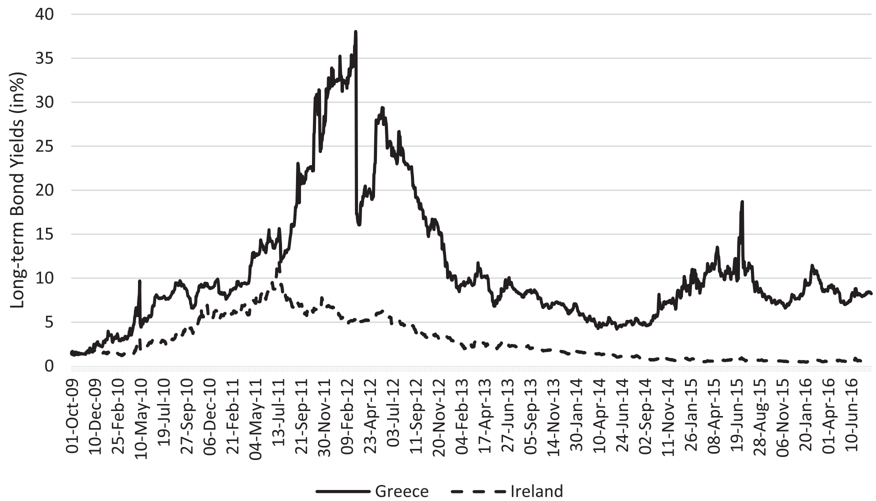

Figure 1. Long-Term Bond Yields of Greece and Ireland from October 1, 2009, to August 12, 2016.

large and highly significant coefficients on the b's. This may reflect the relative longevity of the crises in Greece and Portugal.

The daily, dynamic conditional correlations between the risk premia and the daily volatility in contagion are shown in Figures 1 and 2 (in the on-line appendix). The horizontal line through zero reflects no contagion, with the fluctuations around it suggesting days of high positive correlation (contagion) and other days of negative correlation (safe haven effects). Without exception these daily time-varying correlations are highly volatile, with sharp movements likely reflecting small market developments or investor mood swings. In addition to the daily volatility, the amplitude of the time paths differ. For example, the amplitude of the daily fluctuations is largest for the PIIGS against the safe haven countries, the UK, Switzerland and Sweden and Belgium. The key point is that contagion is time dependent and although the β_1's shown in Tables 2 and 3 report the average correlations over the sample, the charts show that the daily volatility is in general important and much more complex.

The weekly frequency results are shown in Tables 4 and 5 and serve not only as robustness checks on the daily results, but also extend the sample to include the USA and Japan.[9] The sign pattern is not significantly different to the daily data, with the core Euro-zone countries and CEECs all experiencing contagion from the PIIGS, and a predominance of safe haven effects for Switzerland, Sweden and the UK. The new results centre on the USA and Japan. For Japan β_0 is negative, because like Switzerland, Japanese long bond rates are below those in Germany. Although results for β_1 appear inconsistent, the quantile regression model shows a poor fit, and little weight should therefore be put on these specific results. In Table 4 significant safe haven effects are posted for Portugal and Italy, whereas in Table 5 the safe haven effects are for Greece and Ireland. The explanation probably lies in the fact that Japanese long bond rates have been very low for the whole of the sample period and was negative after February 2016. For the USA there are not only significant safe haven effects for Ireland, but also for Spain and Portugal in the M-eGARCH results. The weekly dynamic conditional correlations shown in Figure 3, in the on-line Appendix, indicate persistent safe haven effects for Ireland-USA. In addition, there is period of sustained contagion for several country pairs from early-2013 until mid-2014, soon after between Draghi's announcement to save the Euro and the rise of the Syriza party in Greece. The best examples are perhaps Italy – France, Portugal – Italy and Ireland with Spain, Portugal and Italy, contagion which may in part reflect the cost of saving the Euro.

We undertook two further experiments with this data set. First, we dropped Portugal, Spain and Italy from the crisis country group as sources of contagion, because the extreme values of the interest rate differentials between Greece, Portugal, Spain and Italy are all highly correlated – see Table 1 – and so by excluding the highly correlated source countries we hope to improve the efficiency of the estimates by reducing the degree of multicollinearity. Second, we split the sample at 18th September 2014, to see if the pattern of contagion was any different in the Second Greek crisis to that in the first.

When we focus on extreme negative events (or news) only in Greece and Ireland, the daily data set shows Greece and Ireland are both significant sources of contagion to all Euro-zone and CEECs, whilst Switzerland, the UK and Sweden are safe havens (see on-line appendix, Tables 8A and 8B). On the weekly data the quantile regression estimates (see on-line appendix, Tables 9A and 9B show exactly the same results, but the asymmetric

Figure 2. Dynamic Conditional Correlations from M-EGARCH Models (Daily Data, Static expectations).

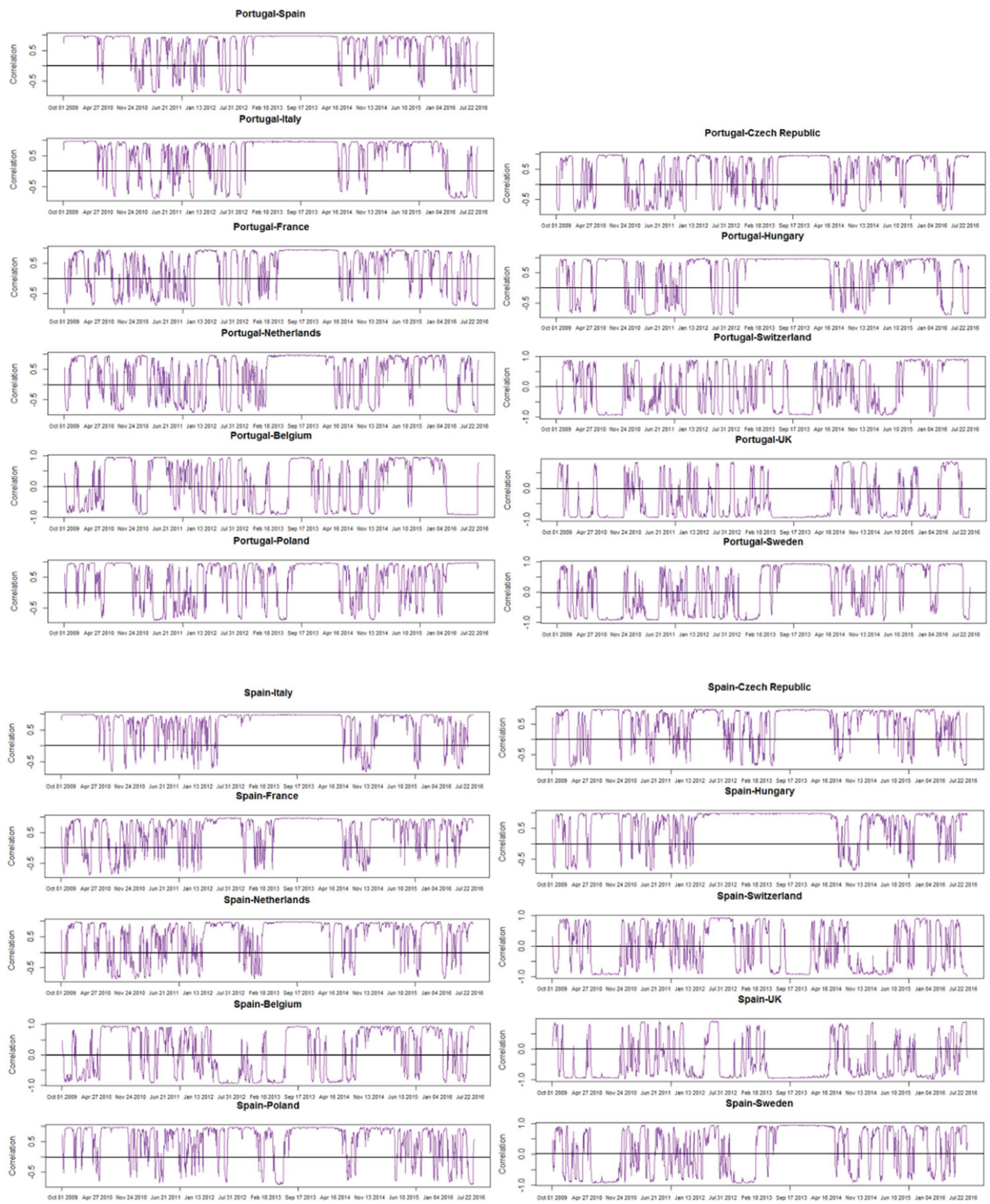

Figure 2. Continued.

GARCH model suggests that Portugal, Italy and France are safe havens for Greece. Both Greece and Portugal have very strong persistence effects from the variance model and no asymmetric news effects. As expected the broad pattern is strongly confirmed for all five PIIGS.

Following Bird et al. (2017a) the sample is split in two to reflect the two Greek crises and the results given in Tables 10A and 10B in the in-line appendix. In the first Greek crisis period, from 1st October 2009 until 18th September 2014, Ireland was a safe haven for Greek investors (together with the US, Sweden, Switzerland and the UK). Hungary was the only country not significantly affected by the crisis. Spain, Portugal and Italy faced most contagion, although Japan was also significantly, but more moderately, affected. In the second Greek crisis period, from 19th September 2014 until 12th August 2016, the contagion effects are generally smaller, although

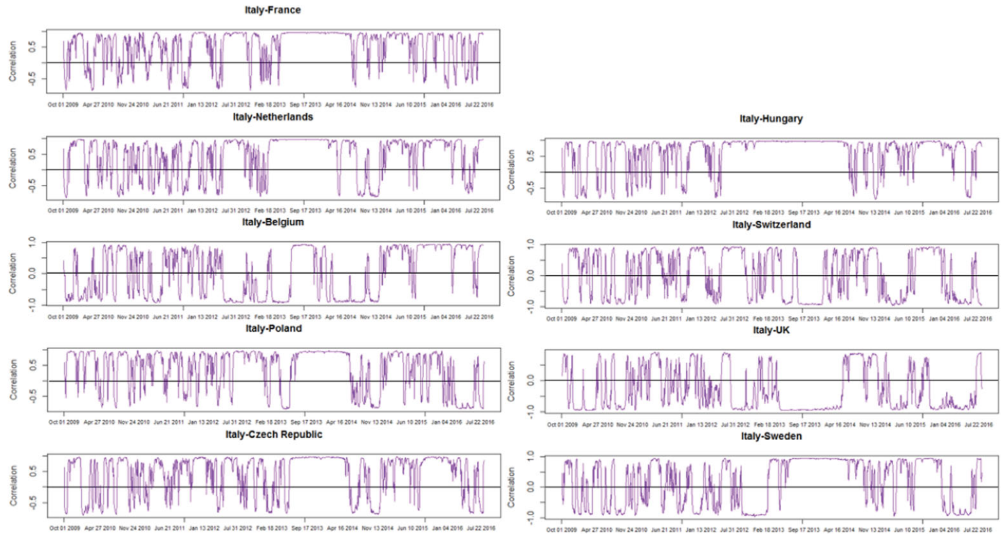

Figure 2. Continued.

still significant and as widespread as previously.[10] However, the safe haven effects are much smaller, with only the USA experiencing a strongly significant one. Notably, in this sub-period Ireland is affected by contagion from Greece and is not a safe haven as it was during the first Greek crisis.

The effects of extreme negative events in Ireland are also very different between the two sub-periods. In the period of the first Greek crisis there is also contagion from Ireland, with Belgium perhaps the most affected of the Euro-zone countries, followed by Greece itself. However, there is no significant contagion to the Euro-zone from Ireland during the second Greek crisis period essentially because the Irish crisis was over before the second Greek crisis began. Contagion from the Irish crisis was shorter-lived than that from Greece.

Analyses of the effects of the crisis in the Euro-zone on non-European countries are an interesting and novel feature of this paper. In terms of impact effects over the whole sample, the USA acted as a safe haven in the case of extreme negative events in Ireland and Spain, but not so much in the case of Greece. However not all non-European countries reveal the same pattern. Thus, while Japan acted as a safe haven when there were extreme negative events in Ireland, it experienced direct contagion from extreme negative events in Greece. The pattern alters when a distinction is made between the first and second crises in Greece since both safe haven and contagion effects were more muted in the case of the second crisis.

5. Factors affecting vulnerability to contagion

Having established distinct patterns of contagion from the Greek and Irish crises, we now try and identify the factors that affect other countries' vulnerability to contagion. What is it that makes a country more or less vulnerable to contagion from an extreme negative effect in another country?

Conceptually we can distinguish two mechanisms. The first operates via effects on trade and capital flows. The second is via expectations; events in one country may directly affect expectations about other countries and hence the pricing of their financial assets. Thus, for example, although the trade effects may operate fairly slowly, expectations of these effects could affect asset prices quickly. Asset prices could thus adjust quickly even in the absence of capital flows, although it is likely that prices would be affected both through expectations effects and through capital flows themselves. For example, with an increase in risk premium risk-neutral investors would not adjust their portfolios assuming that they felt that the increase in the risk premium was sufficient to accurately reflect the increased risk, while more risk-averse investors would pull out. Given these considerations we think it best to think of the factors we investigate as indicators of market perception of vulnerability.

Table 4. Estimation Results from the aDCC – M-eGARCH model (with Static Exchange Rate Expectations and weekly data) Data.

	Mean relation					Variance model				
	β_0	β_{GR}	β_{IR}	β_{PO}	β_{SP}	β_{IT}	b	a	c	γ
Greece	7.91***		1.81***	3.31	1.51***	0.39	0.84***	0.15**	0.13**	
	(0.28)		(0.34)	(12.88)	(0.55)	(0.70)	(0.32)	(0.07)	(0.05)	
Ireland	1.09***	−1.27***		−1.25***	1.55***	1.07***	0.11	0.86***	−0.21**	2.22***
	(0.01)	(0.06)		(0.08)	(0.08)	(0.10)	(0.08)	(0.04)	(0.09)	(0.28)
Portugal	2.20***	1.07***	1.75***		0.55***	−0.16	0.82***	0.17***	0.03*	
	(0.06)	(0.18)	(0.13)		(0.14)	(0.17)	(0.08)	(0.06)	(0.01)	
Spain	1.36***	−0.04***	0.80***	−0.16***		0.07***	0.11	0.85***	−0.41*	1.71***
	(0.01)	(0.001)	(0.02)	(0.01)		(0.001)	(0.19)	(0.09)	(0.23)	(0.50)
Italy	1.35***	−0.12***	0.29***	−0.002	−0.54***		0.12	0.85***	−0.42***	1.61***
	(0.01)	(0.05)	(0.01)	(0.01)	(0.02)		(0.09)	(0.04)	(0.10)	(0.24)
France	0.35***	0.32***	0.02***	0.12***	0.27***	0.07***	−0.02	0.86***	−0.67***	1.31***
	(0.004)	(0.03)	(0.01)	(0.02)	(0.01)	(0.01)	(0.05)	(0.04)	(0.16)	(0.11)
Netherlands	0.19***	0.01	0.09***	0.03***	0.01	0.05***	0.06	0.66***	−2.03***	2.15***
	(0.001)	(0.01)	(0.001)	(0.01)	(0.01)	(0.01)	(0.10)	(0.03)	(0.18)	(0.22)
Belgium	2.50***	0.40***	0.28***	0.77***	−0.05*	0.001	−0.13*	0.85***	−0.42***	2.22***
	(0.01)	(0.01)	(0.04)	(0.01)	(0.03)	(0.03)	(0.07)	(0.04)	(0.05)	(0.16)
Poland	2.26***	0.34***	0.82***	0.05	0.16***	0.24**	0.03	0.80***	−0.57***	1.07***
	(0.02)	(0.08)	(0.04)	(0.10)	(0.01)	(0.10)	(0.06)	(0.06)	(0.15)	(0.14)
Czech Republic	0.33***	0.27***	0.40***	0.05	0.21***	0.13***	0.09	0.74***	−0.95***	1.58***
	(0.02)	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)	(0.07)	(0.06)	(0.21)	(0.20)
Hungary	3.23***	0.37***	0.91***	0.34***	1.75***	0.39***	0.15	0.84***	−0.32***	2.19***
	(0.005)	(0.02)	(0.03)	(0.02)	(0.02)	(0.05)	(0.11)	(0.07)	(0.10)	(0.22)
Switzerland	−0.64***	−0.13***	−0.55***	−0.08***	−0.26***	−0.02	0.12*	0.81***	−0.75***	1.44***
	(0.004)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.06)	(0.04)	(0.15)	(0.19)
U.K.	1.19***	−0.06	−0.66***	0.11	−0.71***	−0.09	−0.01	0.85***	−0.54***	1.34***
	(0.01)	(0.05)	(0.02)	(0.06)	(0.12)	(0.17)	(0.11)	(0.05)	(0.19)	(0.35)
Sweden	0.46***	−0.22	−0.27***	−0.23**	−0.04	0.05	−0.14**	0.75***	−1.12***	1.41
	(0.04)	(0.20)	(0.03)	(0.12)	(0.03)	(0.05)	(0.07)	(0.07)	(0.36)	(0.94)
Japan	−0.30***	0.12**	0.02	−0.60***	−0.05	−0.15***	0.67***	0.32***	0.001**	
	(0.02)	(0.05)	(0.05)	(0.04)	(0.05)	(0.03)	(0.08)	(0.08)	(0.0004)	
U.S.	1.04***	0.21***	−0.74***	−0.05***	−0.74***	−0.02	0.09*	0.87***	−0.50***	1.74***
	(0.005)	(0.004)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.04)	(0.12)	(0.21)

Note: Estimation Results from the aDCC—M—eGARCH-TGARCH and the aDCC-M-eGARCH-NAGARCH models are the same as these.
Note: ***, ** and * indicate the significant levels of 1%, 5% and 10% respectively.
Diagnostics: LL $= 21767.93$, $\lambda_1 = 0.54$ (0.03), $\lambda_2 = 0.29$ (0.04) and $\lambda_3 = 0.01$ (0.005), AIC $= -9.11$, BIC $= -5.90$, H-Q $= -7.83$
Risk premium equations: $\rho_{it} = \beta_0 + \beta_{GR}D_{GR} + \beta_{IR}D_{IR} + \beta_{PO}D_{PO} + \beta_{SP}D_{SP} + \beta_{IT}D_{IT} + \varepsilon_{it}$ where i = Greece, Ireland, Portugal, Spain, Italy, France, Netherlands, Belgium, Switzerland, U.K., Sweden, Japan, U.S., Poland, Czech Republic and Hungary, j = Greece, Ireland, Portugal, Spain, Italy and $\varepsilon_{it}|I_{t-1} \sim N(0, H_t)$. Variance equations $ln(h_{it}) = c_i + b_i ln(h_{it-1}) + \sum_{j=1}^{5} a_{ij} f_j(z_{jt-1})$.

We include two measures of trade openness; first, a country's total trade relative to its GDP, as used by Forbes (2012), and second, a country's trade with Euro-zone countries (relative to GDP). Our expectation is that any one individual country is more likely to encounter contagion from a crisis in the Euro-zone when it trades relatively heavily with the source country or the other countries that are affected. Crises tend to be internationally transmitted, since a decline in national income in one country leads to a fall in its imports and therefore a fall in other countries' exports to that country. For countries that do not belong to the Euro-zone and have a flexible exchange rate there is another route through which trade linkages may operate. A fall in the value of the Euro, for example, will give Euro-zone exporters a competitive advantage in non-Euro zone markets while exporters to the Euro-zone from outside will be disadvantaged by any appreciation in their exchange rate vis-a-vis the Euro. This is likely to give rise to reduced exports sales depending on the value of key foreign trade price elasticities. The capacity for the exchange rate to move against the Euro also means that expectations may be important, as we have already discussed.

In addition to the trade variables, there may be a number of financial linkages by which an extreme negative event in one country affects others. Financial weakness is likely to make a country particularly vulnerable to contagion effects from elsewhere, whereas financial strength may be more likely to induce a safe haven effect.

Table 5. Estimation Results from the Quantile Model (Static Exchange Rate Expectations and weekly data).

							Diagnostics		
	β_0	β_{GR}	β_{IR}	β_{PO}	β_{SP}	β_{IT}	0.25 Pseudo R-square	0.50 Pseudo R-square	0.75 Pseudo R-square
Greece	8.83***		3.76***	7.21***	0.61	7.38***			0.50
	(0.15)		(0.81)	(1.75)	(1.50)	(1.99)			
Ireland	2.58***	-3.34***		6.08***	0.13	0.71**			0.27
	(0.24)	(0.89)		(0.92)	(0.28)	(0.28)			
Portugal	3.85***	1.97**	3.03***		0.97**	1.94***			0.46
	(0.32)	(0.58)	(0.53)		(0.38)	(0.33)			
Spain	2.27***	-0.20	0.10	0.41**		2.04***			0.29
	(0.16)	(0.47)	(0.18)	(0.17)		(0.21)			
Italy	1.81***	0.59***	0.02	1.13***	1.33***				0.42
	(0.14)	(0.15)	(0.16)	(0.13)	(0.16)				
France	0.48***	0.32***	-0.03	0.24	0.15***	0.08			0.41
	(0.03)	(0.10)	(0.12)	(0.16)	(0.04)	(0.07)			
Netherlands	0.20***	-0.01	0.07***	0.09***	-0.002	0.05		0.21	
	(0.01)	(0.03)	(0.01)	(0.02)	(0.03)	(0.04)			
Belgium	2.55***	0.01***	1.64***	0.18	-0.06	-0.03			0.37
	(0.08)	(0.36)	(0.11)	(0.36)	(0.07)	(0.26)			
Poland	2.78***(0	0.38***(0	0.41***(0	0.25(0	-0.15(0	0.29**(0			0.39
Czech	0.35***	0.35***	0.52***	0.16**	0.13*	0.13		0.40	
Republic	(0.03)	(0.09)	(0.06)	(0.08)	(0.07)	(0.08)			
Hungary	4.35***	0.70***	0.65***	0.33	0.46***	0.78***			0.40
	(0.10)	(0.30)	(0.23)	(0.41)	(0.13)	(0.22)			
Switzerland	-0.82***	-0.16*	-0.39***	-0.09	-0.12***	-0.04	0.26		
	(0.02)	(0.08)	(0.02)	(0.07)	(0.04)	(0.09)			
U.K.	1.13***	0.20	-0.58***	-0.17	-0.60***	-0.03		0.39	
	(0.03)	(0.19)	(0.06)	(0.13)	(0.09)	(0.19)			
Sweden	0.53***	-0.04	-0.19***	-0.37**	-0.02	-0.004			0.36
	(0.01)	(0.12)	(0.04)	(0.14)	(0.07)	(0.10)			
Japan	-1.12***	-1.12***	-0.77***	0.07	0.20	0.16	0.18		
	(0.04)	(0.42)	(0.10)	(0.09)	(0.66)	(0.66)			
U.S.	1.54***	0.04	-0.52***	-0.20	-0.12	-0.71			0.37
	(0.02)	(0.31)	(0.18)	(0.34)	(0.44)	(0.47)			

Note: *** and ** indicate the significant levels of 1% and 5% respectively.
Number of observations $= 359$
$\rho_{it} = \beta_0 + \beta_{GR}D_{GR} + \beta_{IR}D_{IR} + \beta_{PO}D_{PO} + \beta_{SP}D_{SP} + \beta_{IT}D_{IT} + \varepsilon_{it}$ where i $=$ Greece, Ireland, Portugal, Spain, Italy, France, Netherlands, Belgium, Switzerland, U.K., Sweden, Japan, U.S., Poland, Czech Republic and Hungary

We include three measures of financial vulnerability, reflecting the soundness of the banking system, the stability of the public finances and global factors, such as the exchange rates and changes in US interest rates.

We use the capital-to-assets ratio of domestic banks as an indicator of the general safety or fragility of the banking system, this is similar to Forbes (2012) banking exposure variable (measured as gross banking assets plus liabilities). In the Euro-zone crises the size of public sector debt outstanding is also likely to be important in contributing to vulnerability. This may directly influence market confidence but will also affect fiscal space and therefore a government's ability to finance fiscal deficits and to neutralize the macroeconomic impact of crises elsewhere. Like Forbes (2012) we also include the change in US interest rate as a way of capturing any transmission effect through US capital markets. If the Euro-crisis is predominantly a European, as opposed to a world-wide phenomenon, we would expect this variable to be insignificant. In addition we also include the depreciation of the Euro against non-Euro zone currencies to try to capture the extent to which nominal exchange rates served to limit non-Euro zone countries' vulnerability to contagion.

The extreme values of the risk premium were converted into a series, y_{jt}, of (0,1) dummies for each of the five crisis countries, which were then stacked. This enables us to estimate a panel, conditional logistic model, with fixed effects, which can be represented as:

$$P(y_{jt} = 1) = \frac{e^{\phi_i + \beta' x_{it}}}{1 + e^{\phi_i + \beta' x_{it}}} \tag{6}$$

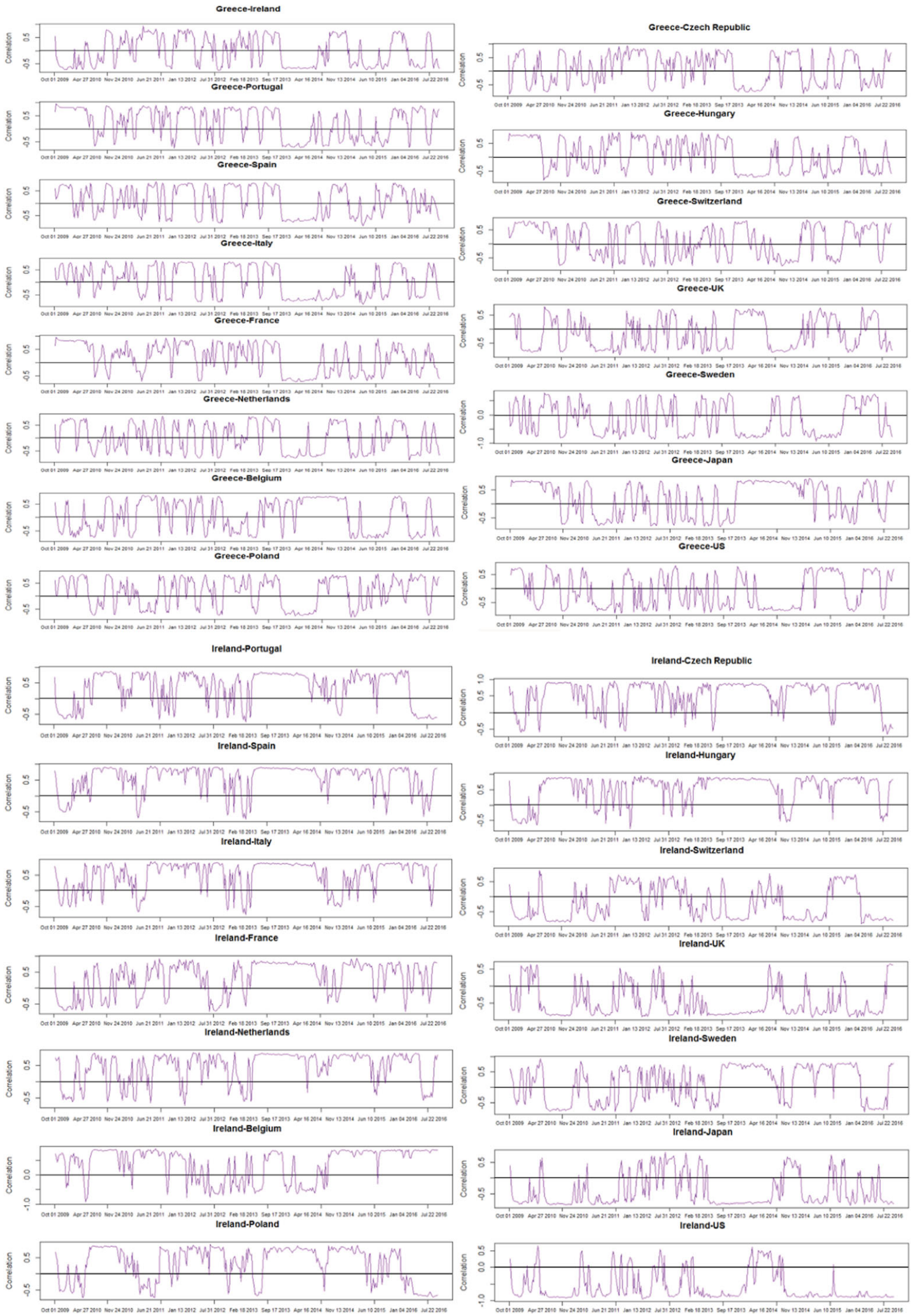

Figure 3. Dynamic Conditional Correlations from M-EGARCH Models (Weekly Data, Static expectations).

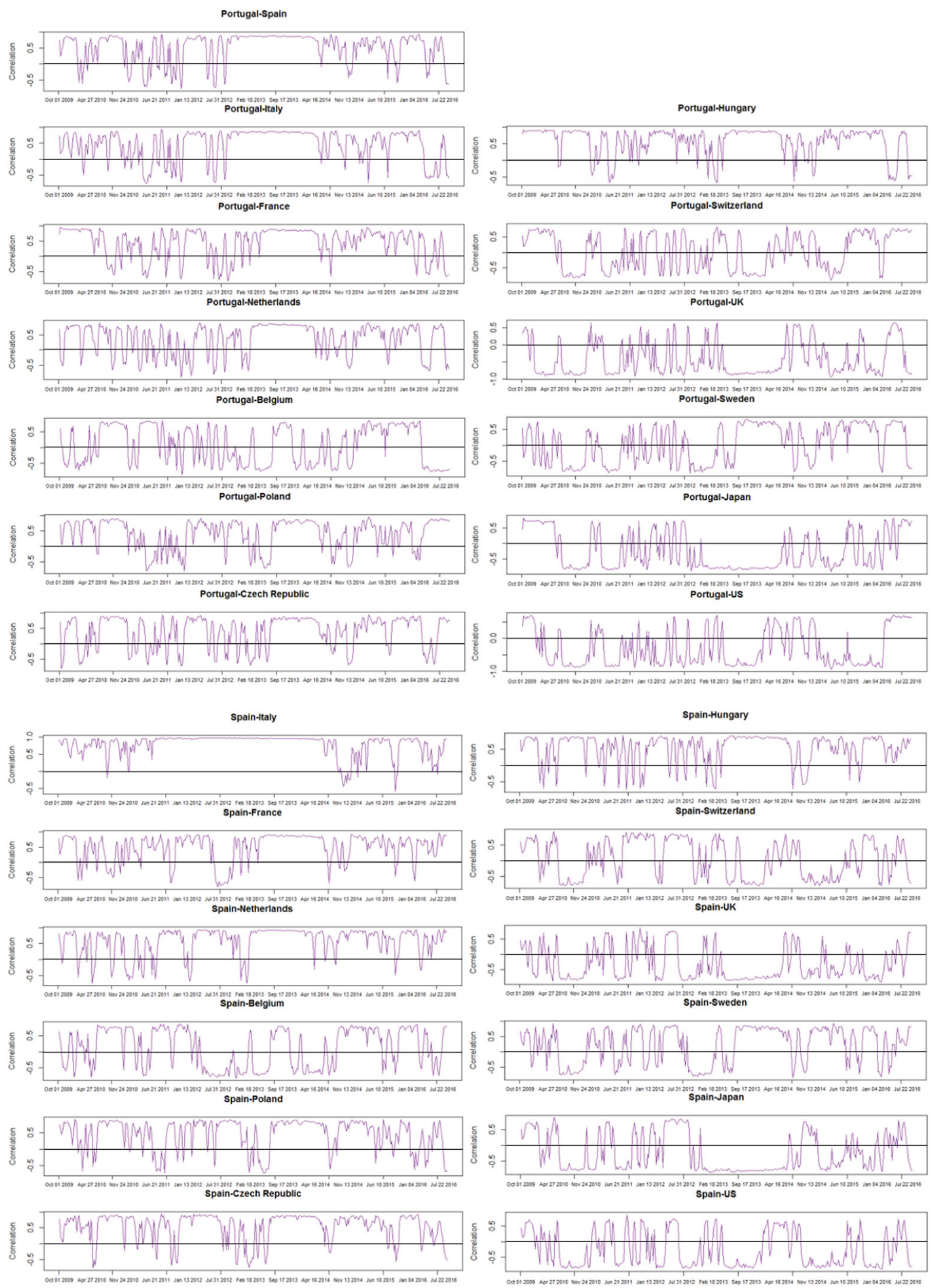

Figure 3. Continued.

where e is the base of natural logarithms, ϕ_i denotes the country fixed effects and the vector of fundamentals, x_{it}, includes both the real side economic variables and financial variables, listed in the notes to Table 6.

Table 6 presents the results from five specifications of the estimated model. The main findings are as follows. First, the change in the US interest rate had no significant effect on the vulnerability to contagion in the sample

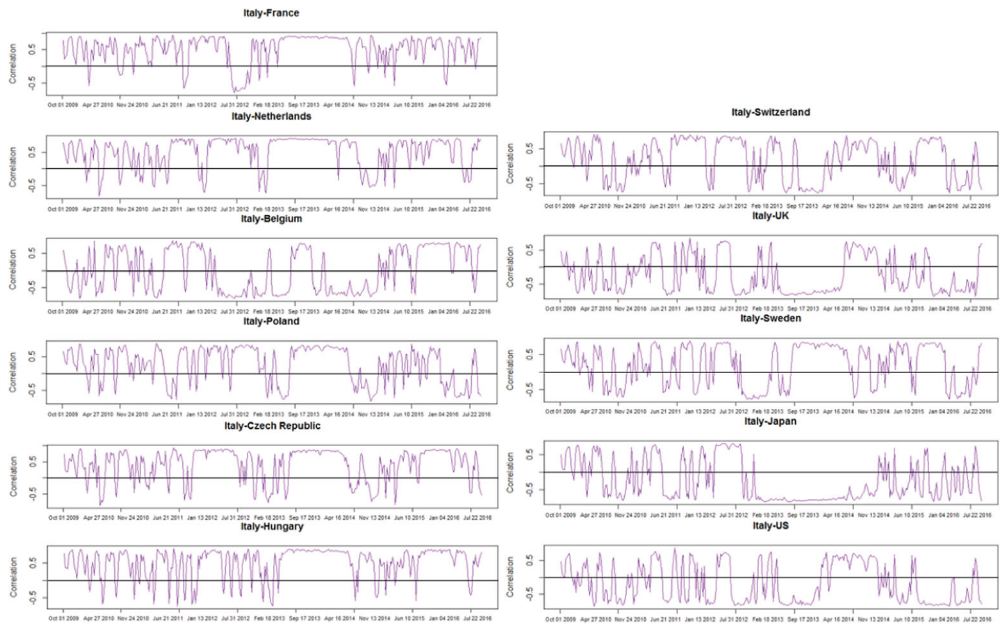

Figure 3. Continued.

countries. Although the USA was a safe haven at the time of the Greek crisis, it played no significant role in the transmission of the crisis back to other EU countries. The exchange rate between the US dollar and the euro may have played a role in this but the effect was statistically insignificant. An appreciation in the Euro had no significant effect on the probability of an extreme negative event occurring. The positive sign on the exchange rate coefficient suggests, however, that euro depreciation would tend to decrease the probability of an increase in risk premia. This result is consistent with the findings of Obstfeld, Ostry, and Qureshi (2017) who find that exchange rate regimes do matter and that countries with fixed rates (or currency boards) are more strongly affected by international financial shocks as they have little autonomy over the design of monetary policy. This is also confirmation of our analysis of contagion which shows that the greater is the fixity of the exchange rate between economies the greater is contagion.

Second, both measures of openness to international trade have positive signs, indicating that the probability of an extreme negative event is marginally higher for a country that trades relatively heavily with other economies in the Euro zone. The measures are statistically significant in all specifications of the model although, as expected, the intra Euro-zone trade is slightly more important than global openness.

Third, the most robust finding relates to financial variables in the transmission process. The stock of public sector debt outstanding relative to GDP is positively signed and statistically significant in all specifications. This is not surprising given the large role that fiscal problems played in the crisis. A unit rise in the stock of public debt raises the probability of an extreme event by about 2.5 to 3 per cent. This is the principal and most consistent channel of contagion through the bond markets in the financially integrated European Union. The importance of the banks' capital-to-assets ratio, however, is not always significant. Its significance depends on the measure of openness used in the model. When intra Euro-zone trade is used then it is not significant, but if general global openness is used then it is statistically significant. This suggests that Euro-area banking sector assets are linked with intra-EU trade, but that there are distinct channels through which contagion may spread.

In Table 6, a downgrade of a country's debt by the rating agencies has by far the strongest effect, such that a downgrade leads to an increase in the probability of contagion of 100 per cent. This is in conflict with the strong form of the efficient markets view that most of the information influencing the decisions by the ratings agencies would have already been detected and priced by the market.

Table 6. The Drivers of Contagion.

Specification:	A	B	C	D	E
EXTR	0.0029***		0.0028***		0.0028***
	(5.43)		(5.32)		(5.40)
OPEN		0.0011**		0.0010**	
		(2.67)		(2.50)	
ER	0.0146	0.0281	0.0100	0.0144	0.0087
	(0.15)	(0.16)	(0.07)	(0.09)	(0.06)
DEBT	0.2799**	0.241*	0.312***	0.2771**	0.2992**
	(2.04)	(1.87)	(2.25)	(2.11)	(2.17)
EXBANK	0.0009	0.0034***	0.0008	0.0034***	0.0008
	(1.03)	(4.26)	(0.87)	(4.29)	(0.97)
USINT	−0.113	−0.1097	−0.1219	−0.1178	
	(−1.01)	(−1.00)	(−1.02)	(−1.02)	
DOWN			1.0788**	1.1265***	1.0676**
			(2.96)	(3.25)	(2.93)
LL stat	*−276.37*	*−294.112*	*−272.275*	*−289.213*	*−272.864*
LR(χ^2)	*180.12****	*158.27****	*188.32****	*167.95****	*187.14****

Notes: Conditional fixed effects logistic regressions grouped by country. Variables are defined as: **EXV**, the dependent variable, is a dummy variable with value 1 if a country has an extreme negative events and 0 otherwise; ENR^{all} is the percent of the sample with an extreme negative value in the given month; **EXTR** = trade between the individual countries and the Euro-zone ((imports from the Euro-zone + exports to the euro-zone) / GDP)*ENR^{all}; **OPEN** = general openness of individual countries trade (total imports + total exports)/ GDP) * ENR^{all}; **EXBANK** = bank capital to assets ratio (%) * ENR^{all}; **DEBT** = government debt to GDP ratio; **USINT** = US interest rates measured as changes in the interest rate on a 10-year constant maturity government bond; **ER** = *appreciation* of the Euro against individual countries' local currency; **DOWN** = downgrades of an individual country's credit rating.

***, ** and * indicate the significance levels of 1%, 5% and 10% respectively. LR is the likelihood ratio test for equation significance, which is distributed as chi-squared with 5 or 6 degrees for freedom.

6. Concluding remarks

Contagion from financial crises has been an increasingly common phenomenon in the world economy. Given its potential implications, it is important to understand the extent and pattern of contagion, not least in order to design policies that minimize its disruptive consequences. In this paper we have examined various dimensions of contagion in the context of the crisis in the Euro-zone in the period 2009–2016.

We examine the effects of extreme negative events in a number of crisis countries and find that the contagion effects of these events have been particularly significant for other Euro-zone countries, although some countries (notably the crisis ones themselves) have been affected to a greater extent than others. However, not all crises have had similar consequences for contagion. In particular, there have been discernible differences between Ireland and the other crisis countries. Again, the policy implications are important. The policies pursued by Ireland seem to have been more successful both in terms of overcoming the crisis and in reducing its longer run effect, if not its impact effect, on other countries. This came at the price, however, of hitting the Irish public with the huge government debt resulting from the bailout of banks and investors. The balance of these costs and benefits including effects on moral hazard are now a major issue of debate.

Beyond this, we find that European countries that are currently outside the Euro-zone, but have a stated intention of joining it, have also been adversely affected by contagion.

We find that the extent and pattern of contagion changes over time. In most cases the contagion resulting from the second crisis in Greece that we identify as starting in September, 2014, was more muted. In part, this could be because other countries had devised methods of making themselves less vulnerable to it. Moreover, markets appear to have perceived that the risks of the Euro-zone collapsing had diminished. This would imply that the European institutions, in general and the ECB in particular, can influence the degree of contagion from extreme negative events in member countries (see, for example, Kosmidou et al. 2019).

We examine the factors that affect the probability of an extreme negative event occurring and therefore also affect a country's vulnerability to contagion. Overall, we discover that financial variables are more significant than trade ones. We also discover modest evidence that a flexible exchange rate may serve to diminish contagion to some degree. In the ongoing debate about the relevance of the international macroeconomic policy trilemma, this provides some support for the claim that exchange rates continue to play a positive, but only weakly significant role in helping to partially insulate economies from external financial crises.

Other policy conclusions are at one and the same time both straightforward and complex. The straightforward part is that it is important to strengthen the banking and financial sectors and keep indebtedness below a level at which it is perceived as becoming unsustainable. The complex part is that this may mean circumstances arise where the use of expansionary fiscal policy to offset the spill-over effects from a financial crisis elsewhere in the domestic real economy may, at the same time, increase a country's vulnerability to contagion from future external financial crises. In addition to this, while one of the purposes of the Euro-zone is to encourage trade between member states, increasing intra Euro-zone trade makes countries more vulnerable to future contagion from crises elsewhere in the zone. Increasing Euro-zone trade therefore needs to be accompanied by policies designed to reduce the risks of financial crises and financial contagion.

Notes

1. For an analysis of the various types of contagion see Forbes and Rigobon (2002), Forbes (2012), Metiu (2012), Ludwig (2014), Mink and de Haan (2013), and Cronin, Flavin, and Sheenan (2016).
2. Since the model is only estimated over the crisis period, the average level of risk is likely to be higher than in a non-crisis period and so the value of β_{0i}, is also likely to be a little higher. This, however, is not important to the argument here.
3. This assumes that flows out of the crises countries into Germany do not have a significant effect on German interest rates, which are used to capture global capital market factors.
4. 1st October 2009 is selected as the start date because it marked the beginning of the permanent deviation of Greek rates from German rates. From the start of the Euro until 2009 the average deviation between Greek and German 10-year bond rates was about 0.26%. In October 2009 the deviation was about 1.36% as the sharp upward trend in Greek rates began, which we take to mark the beginning of the first Greek crisis.
5. We proxy changes in the expected exchange rate in two ways: as either static (no expected change) or perfect foresight (instantly and fully adjusted). If daily exchange rate expectations are constant then $x_{\mathrm{t}} = 0$, whereas in the case of perfect foresight expectations $x_{\mathrm{t}} = ((e_{\mathrm{t}+1} / e_{\mathrm{t}})\text{-}1)\mathrm{x}\ 100$, where e_t is the spot exchange rate.
6. We also experimented with extreme values of two standard deviations from the mean, but this left us with very few values.
7. A (0, 1) dummy variable was created, in which the one's denoted each individual news event. This series was then correlated with each of the five the countries series of values of their extreme risk premium. Table 1 reports the simple correlation coefficients from this exercise.
8. See Higgins and Bera (2017) for an alternative analysis of contagion that also discusses 'flight to quality' effects.
9. The very similar results with perfect foresight exchange rate expectations are presented in Tables 7A and 7B in the on-line appendix.
10. The statement by Mario Draghi in July 2012 that the ECB would do 'whatever it takes' to save the Euro seemed to bring the acute phase of the first crisis to an end. In April 2013 the Greek parliament approved further economic reforms and in November Moody's upgraded Greece's crediting rating as did Fitch in May 2014. However the growing popularity of the anti-austerity Syriza party sowed the seeds for a second crisis. This can be timed from mid-September 2014 when the leader of the Syriza party announced that he would bring austerity to an end. The crisis peaked in July 2015 but abated as tensions between Greece and its creditors eased and the Greek parliament approved new austerity measures as a precursor to further bailout funds. Detailed statistical support for the identification and timing of the two crises is provided by Bird et al. (2017a).

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