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Impact of QE on European sovereign bond market

Franck Martin
Université de Rennes 1, CREM CNRS, France

Jiangxingyun Zhang
Université de Rennes 1, CREM CNRS, France

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Impact of QE on European sovereign bond market equilibrium*

Franck Martin[†], Jiangxingyun Zhang[‡]

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Abstract

This paper tries to evaluate the impact of the ECB's QE programs on the equilibrium of European sovereign bond markets. For this purpose, we develop an original theoretical model to understand the formation of long-term sovereign rates in the euro area. Precisely, it's an international bond portfolio choice model with two countries which generalizes the traditional results of the term structure interest rates theory. Particularly, except for traditional properties, long-term equilibrium rates depend as well as on the anticipated variances and covariances, considered as a component of a volatility risk premium, of future bond yields. By using CDS as a variable to control default risks, the model is tested empirically over the period January 2006 to September 2016. We can conclude that the ECB's QE programs beginning from March 2015, have accelerated the "defragmentation process" of the European bond markets, already initiated since the OMT. However, according to the test à la Forbes and Rigobon, it seems difficult to affirm that QE programs have led to a significant increase in the conditional correlations between bond markets. In a supplementary empirical test, we show that QE has significantly reduced the sensitivities of bond yield spreads to the premiums paid on sovereign CDS.

Keywords: QE impact, Term structure interest rates, Forbes and Rigobon test, Volatility risks, Credit default risks and CDS.

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[†]University of Rennes 1 and CREM-CNRS.

[‡]University of Rennes 1 and CREM-CNRS.

1 Introduction

The ECB's QE programs launched in March 2015 is an essential but paradoxical experience. It is essential because it is the very first experiment conducted in the euro zone, while the United States, Japan and the United Kingdom have already some experiences with this type of unconventional monetary policy. In the euro area, QE1 programs from March 2015 and QE2 from March 2016, represent the only available economy policies to fight against the deflation risks in a context in which fiscal policies are restrictive and focused on reducing public deficits and debts following the implementation of the new European fiscal compact on 1 January 2013.

The experience of QE in the euro zone is also paradoxical because the brokers' opinion seems to be convinced that the large-scale government bond purchase programs allow the ECB having a effective control of long-term sovereign rates. Therefore, we would have switched to a fixed rate regime which is not only guided by short-term rates via the REFI rate but also by the long-term rates through the bond purchases of the ECB. When the fears of "tapering" are stronger, the occasional rising of long-term interest rates show that market operators are also convinced of the ECB's capacity to maintain sovereign bond yields close to zero. The paradox comes precisely from the fact that the academic literature is much more nuanced than the brokers' opinion on the effectiveness of QE programs, including the first transmission mechanism that the effective control of long-term interest rates determinates the financial costs of sovereign states.

De Santis (2016) point out that studies on the US bond market estimate that bond purchases from the FED between December 2008 and March 2010 have contributed to decrease long-term government rates by about 90 basis points.[1] Comparable purchases by the BoE in the United Kingdom have reduced long-term rates by 50 basis points between March 2009 and January 2010.[2] While evaluating the impact of monetary policy announcements of the ECB relayed by Bloomberg between September 2014 and February 2015, before the implementation of the APP, De Santis (2016) considers that the monetary policies of the ECB have reduced the GDP-weighted European long-term rate by 63 basis points, with more pronounced effects on the most vulnerable countries. These are the ex-ante effects related to the APP announcement. Valiante (2016) considers that ex-ante effects are as important as ex-post effects, once asset purchases are conducted. From a Double Difference Method (DDIF) on a market panel that has undergone solely QE treatment, he estimates that the contribution of the APP to the decrease of euro area bond rate is about 1 percent.

Overall, whether in the USA, the UK or the euro zone, we find that the contribution of QE to the decline in sovereign rates is not very significant, and even rather more modest for the euro area since the announcement of QE in September 2014 until September 2016 (Figure 1). This might suggest that other mechanisms may have played a role in this process: effects of deflation risks on nominal rates (fisher effect), significant improvement of sovereign issuers and etc.

[1] Most of the empirical literature on asset purchases by the Federal Reserve (FED) and Bank of England (BoE) has focused on their effects on government bond markets. Studies focusing on the US government bond yields are Doh (2010), Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), Meaning and Zhu (2011), D'Amico and King (2013),d'Amico et al. (2012) and Li and Wei (2012).

[2] Studies focusing on the UK government bond yields are Meier (2009), Joyce et al. (2011), Joyce and Tong (2012), Meaning and Zhu (2011), Breedon et al. (2012), Christensen and Rudebusch (2012) and McLaren et al. (2014).

Table 1: Asset purchase programmes in practice

History of cumulative purchases under the APP. End of month, in euro millions. Holdings are end-of-month book value at amortised cost. Source: European Central Bank

		Monthly net,purchases at book value				Quarter-end, amortisation adjustment	Quarter-end, amortisation adjustment	Quarter-end, amortisation adjustment	Quarter-end, amortisation adjustment	Holdings			
		Asset-backed securities purchase programme	Covered bond purchase programme 3	Corporate Sector purchase programme	Public sector purchase programme	Asset-backed securities purchase programme	Covered bond purchase programme 3	Corporate Sector purchase programme	Public sector purchase programme	Asset-backed securities purchase programme	Covered bond purchase programme 3	Corporate Sector purchase programme	Public sector purchase programme
2014	October	0	4.768	0	0	0	0	0	0	0	4.768	0	0
	November	368	13.033	0	0	0	0	0	0	368	17.801	0	0
	December	1.376	11.885	0	0	0	-54	0	0	1.744	29.632	0	0
2015	January	582	10.623	0	0	0	0	0	0	2.326	40.255	0	0
	February	1.137	10.953	0	0	0	0	0	0	3.463	51.209	0	0
	March	1.158	12.587	0	47.383	0	-190	0	-27	4.622	63.606	0	47.356
	April	1.163	11.464	0	47.701	0	0	0	0	5.785	75.07	0	95.057
	May	1.42	10.039	0	51.622	0	0	0	0	7.205	85.108	0	146.679
	June	1.59	10.215	0	51.442	1	-326	0	-592	8.796	94.997	0	197.53
	July	943	9.006	0	51.359	0	0	0	0	9.739	104.003	0	248.889
	August	1.348	7.459	0	42.826	0	0	0	0	11.087	111.462	0	291.715
	September	1.928	10.11	0	51.008	0	-422	0	-1.261	13.015	121.151	0	341.462
	October	1.563	9.993	0	52.175	0	0	0	0	14.577	131.144	0	393.637
	November	601	6.869	0	55.105	0	0	0	0	15.178	138.013	0	448.742
	December	145	5.803	0	44.309	-1	-476	0	-1.836	15.322	143.34	0	491.215
2016	January	2.26	7.197	0	52.956	0	0	0	0	17.582	150.537	0	544.171
	February	989	7.784	0	53.358	0	0	0	0	18.571	158.321	0	597.529
	March	418	7.819	0	53.059	1	-503	0	-2.565	18.991	165.638	0	648.022
	April	-16	6.615	0	78.499	0	0	0	0	18.975	172.253	0	726.521
	May	84	5.556	0	79.673	0	0	0	0	19.059	177.809	0	806.194
	June	526	6.098	6.401	72.072	0	-530	-3	-3.064	19.585	183.377	6.398	875.201
	July	783	3.258	6.816	69.65	0	0	0	0	20.368	186.634	13.214	944.852
	August	-226	3.504	6.707	50.513	0	0	0	0	20.142	190.139	19.921	995.364
	September	530	4.731	9.872	69.972	0	-566	-72	-4.093	20.672	194.304	29.722	1.061.244
	October	589	3.437	8.422	72.974	0	0	0	0	21.261	197.741	38.144	1.134.218
	November	1.253	4.993	9.036	70.145	0	0	0	0	22.514	202.734	47.18	1.204.362
	December	317	1.369	4.042	55.032	-1	-588	-152	-4760	22.83	203.516	51.069	1.254.635

Table 2: Breakdown of debt securities under the Public Sector Purchase Programme: Monthly net purchases and WAM of PSPP portfolio holdings

Book value in euro million. Note: Figures may not add up due to rounding. When assessing the remaining WAM of Eurosystem holdings relative to a market measure, deviations could reflect inter alia the 2 to 30 year maturity range of purchases, the issue share limits taking into account holdings in other Eurosystem portfolios as well as the availability and liquidity conditions in the market during the implementation period. Source: European Central Bank

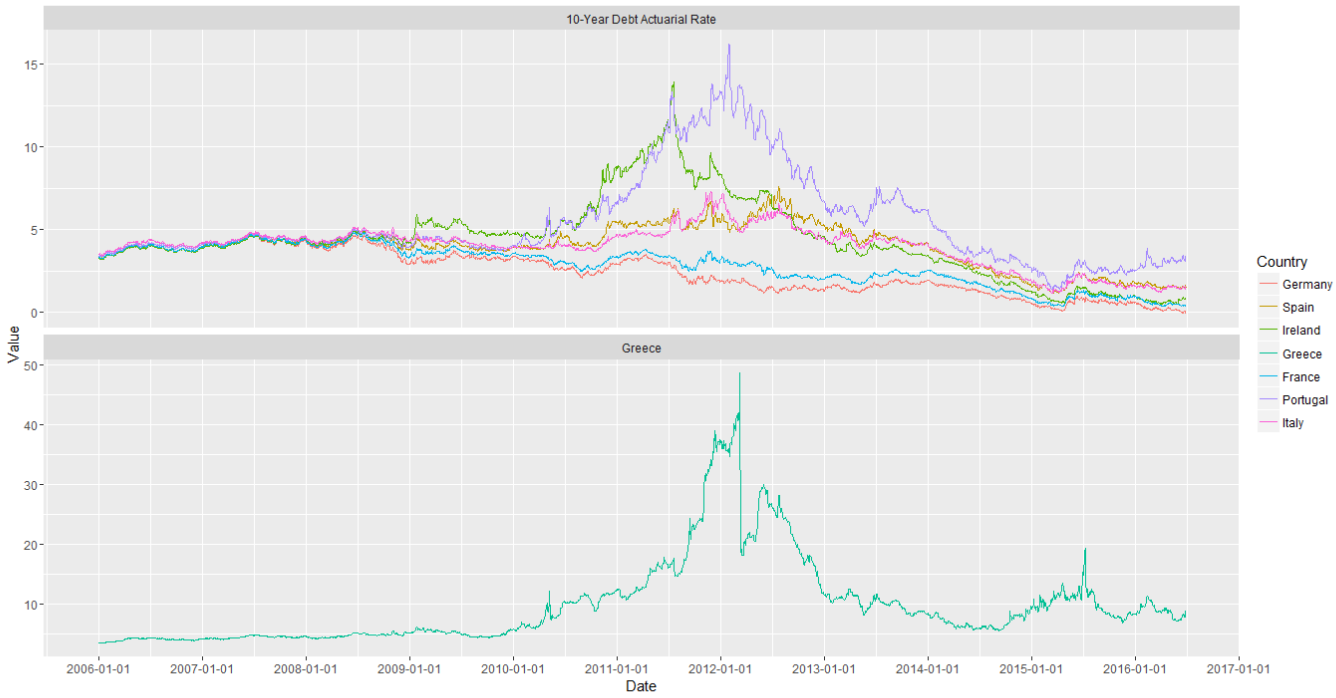
Monthly net purchases

	31/03/2015	30/04/2015	31/05/2015	30/06/2015	31/07/2015	31/08/2015	30/09/2015	31/10/2015	30/11/2015	31/12/2015	31/01/2016	29/02/2016	31/03/2016	30/04/2016	31/05/2016	30/06/2016	31/07/2016	31/08/2016	30/09/2016	31/10/2016	30/11/2016	31/12/2016	cumulative
Austria	1,216	1,205	1,314	1,31	1,363	1,064	1,279	1,324	1,411	1,155	1,348	1,359	1,353	2,06	2,14	1,849	1,878	1,354	1,884	1,959	1,88	1,495	33,197
Belgium	1,528	1,53	1,656	1,657	1,642	1,362	1,633	1,678	1,764	1,446	1,709	1,707	1,71	2,612	2,695	2,341	2,368	1,704	2,377	2,477	2,372	1,867	41,836
Cyprus	0	0	0	0	98	0	0	90	97	0	0	0	-16	0	0	0	0	0	-21	0	0	0	248
Germany	11,07	11,148	12,144	11,97	11,975	9,926	11,851	12,195	12,903	10,443	12,347	12,44	12,411	18,985	19,573	16,888	17,247	12,368	17,188	18,016	17,29	13,568	303,945
Estonia	0	0	0	5	15	10	8	3	7	0	6	7	0	5	0	0	0	0	0	0	0	0	65
Spain	5,447	5,471	5,909	5,915	5,891	4,882	5,789	6,042	6,334	5,137	6,107	6,125	6,111	9,318	9,619	9,238	8,453	6,112	8,487	8,827	8,461	6,656	150,333
Finland	774	786	841	836	850	687	825	844	909	734	865	879	871	1,324	1,366	1,224	1,197	871	1,205	1,258	1,206	939	21,293
France	8,757	8,624	9,485	9,426	9,465	8,087	9,485	9,95	10,221	8,267	9,969	9,989	9,852	14,933	15,398	13,683	13,569	9,769	13,609	14,16	13,48	10,689	240,868
Ireland	722	735	775	784	771	639	824	809	840	684	782	803	808	1,078	1,112	1,085	986	697	982	1,022	979	648	18,562
Italy	7,609	7,585	8,228	8,164	8,248	6,719	8,234	8,365	8,876	7,181	8,559	8,499	8,53	12,998	13,442	12,772	11,867	8,476	11,808	12,323	11,707	9,417	209,605
Lithuania	39	83	123	133	126	143	125	114	117	104	109	109	125	104	113	105	72	48	73	125	99	75	2,262
Luxembourg	183	205	84	261	80	86	138	6	30	42	169	110	144	35	16	26	6	0	10	3	75	34	1,743
Latvia	75	177	205	46	22	23	19	63	31	23	41	30	44	76	58	90	27	72	45	90	39	16	1,315
Malta	5	53	85	66	24	11	18	11	2	7	60	21	60	60	66	37	12	11	7	37	99	55	807
the Netherlands	2,487	2,527	2,667	2,663	2,657	2,213	2,603	2,721	2,883	2,191	2,84	2,794	2,759	4,224	4,355	3,781	3,834	2,915	3,842	3,996	3,831	3,041	67,825
Portugal	1,074	1,084	1,174	1,164	1,16	966	1,148	1,184	1,248	1,018	1,197	1,214	1,213	1,405	1,451	1,438	958	722	1,022	1,021	1,023	726	24,61
Slovenia	209	219	231	228	232	192	227	245	248	197	252	280	237	236	242	254	223	153	219	225	216	168	4,935
Slovakia	506	522	529	546	442	423	467	377	533	277	575	554	433	329	323	233	221	123	133	164	230	216	8,155
Supranationals	5,682	5,748	6,173	6,267	6,3	5,393	6,335	6,153	6,65	5,403	6,021	6,437	6,413	8,717	7,706	7,028	6,732	5,117	7,102	7,271	7,157	5,425	141,229
Total	47,383	47,701	51,622	51,442	51,359	42,826	51,008	52,175	55,105	44,309	52,956	53,358	53,059	78,499	79,673	72,072	69,65	50,513	69,972	72,974	70,145	55,032	1,272,832

WAM of PSPP portfolio holdings

	31/03/2015	30/04/2015	31/05/2015	30/06/2015	31/07/2015	31/08/2015	30/09/2015	31/10/2015	30/11/2015	31/12/2015	31/01/2016	29/02/2016	31/03/2016	30/04/2016	31/05/2016	30/06/2016	31/07/2016	31/08/2016	30/09/2016	31/10/2016	30/11/2016	31/12/2016
Austria	7.79	7.99	7.84	7.74	7.92	8.03	8.01	8.11	8.25	8.52	8.37	8.43	8.51	8.71	8.7	8.92	9.11	9.23	9.32	9.38	9.32	9.26
Belgium	8.8	9.1	9.13	9.09	8.84	8.8	9	9.21	9.62	9.51	9.53	9.59	9.74	9.79	9.78	9.65	9.79	9.92	10	10.07	9.98	10.04
Cyprus					5.41	5.32	5.24	5.43	5.91	5.82	5.74	5.66	5.52	5.44	5.36	5.27	5.19	5.1	5.09	5.01	4.92	4.86
Germany	8.12	7.9	7.11	6.87	6.91	7.09	6.96	6.98	7.02	7	7	6.96	7.05	7.18	7.31	7.44	7.60	7.69	7.88	8	8.06	8.16
Estonia				3.05	2.96	2.87	2.78	2.71	2.63	2.54	2.46	2.38	2.28	2.2	2.13	2.04	1.96	1.87	1.78	1.71	1.62	1.56
Spain	11.66	9.73	9.71	9.82	9.66	9.68	9.68	9.66	9.74	9.7	9.77	9.75	9.68	9.61	9.66	9.73	9.71	9.64	9.57	9.47	9.37	9.27
Finland	7.26	7.15	7.16	7.24	7.25	7.33	7.39	7.51	7.61	7.59	7.6	7.72	7.67	7.6	7.58	7.53	7.55	7.56	7.61	7.65	7.44	7.38
France	8.22	7.84	7.83	7.83	7.93	7.87	7.84	7.83	7.81	7.73	7.69	7.69	7.67	7.68	7.68	7.65	7.71	7.7	7.75	7.8	7.73	7.71
Ireland	9.43	9.14	9.61	9.55	9.77	9.66	9.1	8.98	9.34	9.4	9.48	9.49	9.42	9.47	9.38	9.38	9.31	9.25	9.38	9.35	9.19	9.19
Italy	9.07	8.41	8.68	8.83	9.03	9.12	9.27	9.29	9.28	9.27	9.33	9.34	9.35	9.36	9.31	9.29	9.24	9.2	9.15	9.07	8.95	8.92
Lithuania	6.46	5.22	6.11	5.9	5.69	5.55	5.4	5.36	5.64	6.01	6.24	6.47	6.7	6.61	6.57	6.62	6.50	6.42	6.41	6.6	6.61	6.59
Luxembourg	7.01	6.88	6.71	6.41	6.29	6.26	6.29	6.15	6.13	6.07	6.08	6.1	6.16	6.09	6.01	5.98	5.90	5.81	5.74	5.66	5.52	5.47
Latvia	6.43	5.93	6.3	6.23	6.13	6.07	5.96	6	5.88	5.85	5.7	5.58	5.45	5.37	5.66	6.62	6.56	6.59	6.57	7.32	7.29	7.26
Malta	10.37	8.47	11.05	12.01	11.03	10.49	9.99	9.7	9.6	9.62	9.58	9.53	10.4	10.15	10.57	10.87	10.89	10.75	10.81	11.12	11.54	11.57
the Netherlands	6.71	6.97	6.85	6.82	6.72	6.64	6.6	6.56	6.59	6.51	6.51	6.7	6.86	7.15	7.4	7.57	7.71	7.76	7.9	8.01	8.01	8.02
Portugal	10.96	10.77	10.84	10.61	10.59	10.77	10.86	10.64	10.57	10.36	10.22	10.12	10.18	10.17	10.21	10.14	10.07	9.91	9.84	9.8	9.68	9.53
Slovenia	6.33	7.92	7.5	7.57	7.21	7.73	8.04	8.05	8.13	7.97	7.74	7.57	7.74	8.09	8.32	8.27	8.23	8.25	8.41	8.56	8.71	8.9
Slovakia	9.49	9.26	9.29	9.21	8.85	8.66	8.66	8.47	8.54	8.58	8.41	8.33	8.24	8.24	8.11	8.02	7.92	7.85	7.86	7.83	7.79	7.9
Supranationals	7.26	8.05	7.8	7.43	7.19	7.05	6.88	6.9	7.05	6.97	6.91	7.03	6.92	6.79	6.83	6.86	7.06	7.12	7.27	7.33	7.25	7.31
Total	8.56	8.25	8.07	8	8	8.03	7.99	8	8.06	8.02	8.02	8.03	8.05	8.08	8.13	8.18	8.26	8.28	8.35	8.38	8.33	8.33

Figure 1: 10-Year Bond Rates



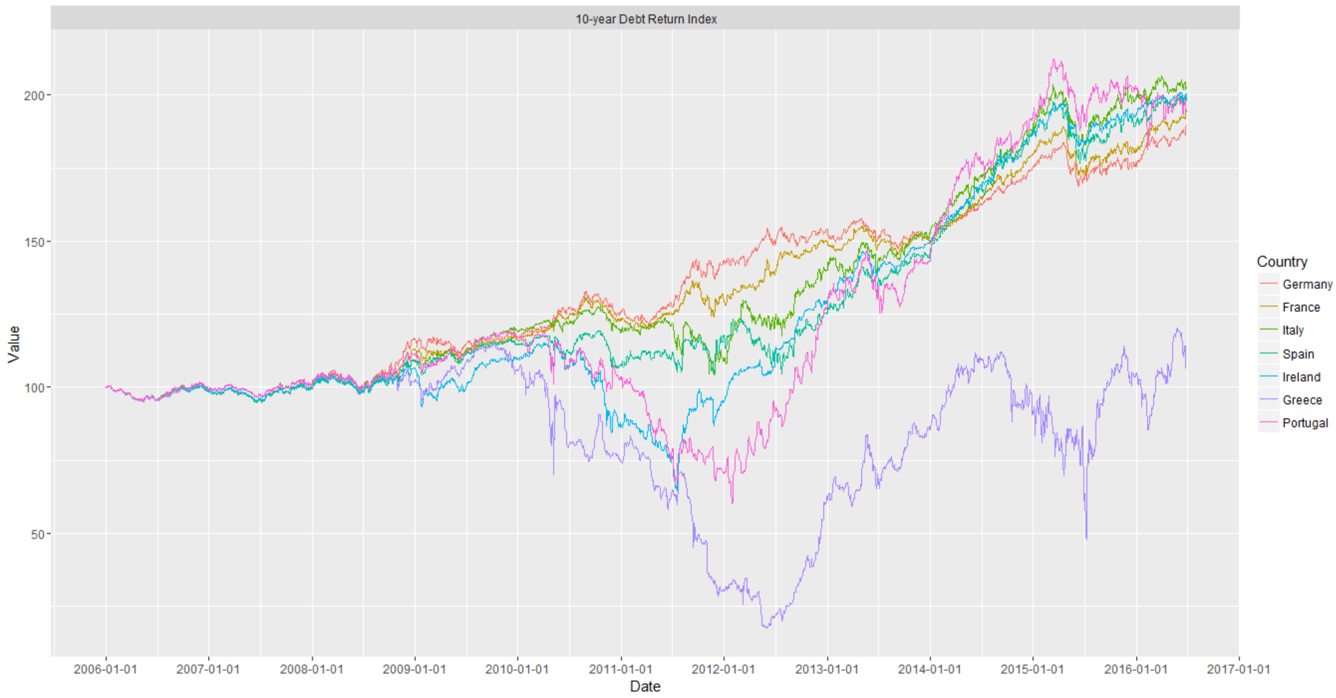
Our contribution to the debate on the impact of QE on the bond market equilibrium can be summarized as follows. We use an original theoretical model developed by Martin and Zhang (2016) to identify the normal mechanisms of bond markets and the potential effects of asset purchases by the ECB. It is an international bond portfolio choice model with two countries, typically a country with little default risks (core countries in the zone) and a more vulnerable country (periphery countries). Optimal bond demands are not only confronted with the supply of bonds based on the evolution of public deficit and debt, but also to the ECB's purchases which effectively reduce the net supply of bonds in circulation.

The properties of the equilibrium model thus generalize the traditional term structure of interest rates theory (Mankiw et al. (1986), Shiller and McCulloch (1987), Walsh (1985), Jones and Roley (1983), Artus (1987)). Long-term equilibrium rates depend crucially not only on the variances but also on the anticipated covariances of the bond yields of the two countries. Therefore, the expression of volatility risk premium is enriched by a covariance effect, that is to say the joint risks between markets. Thus, we point out from a theoretical point of view that the purchases of the ECB have an effect on the rates which depends on the sign of the covariances anticipated by investors.

The model is estimated econometrically over the period January 2006 to September using daily data. The anticipated variances and covariances of the bond yields are simulated by using a bivariate DCC-GARCH model with a 500-day rolling window. Risk forecasts are given by the one-step-ahead forecasts of variances and covariances. The default risk is controlled by introducing the premium of sovereign CDS. Finally, a global uncertainty variable, Vstoxx index and short-term rates in euro area rated AAA complete the set of explanatory variables of sovereign bond rates.

We estimate 21 pairs of European countries in a framework of conditional heteroscedasticity with a VECH specification matrix of variance-covariance for innovations. Estimations are performed over several periods plus a series of estimations with 500-day rolling windows in order to evaluate possible deformation of the market mechanisms over the post-crisis period with the implementation of the OMT and APP by the ECB. Finally, by applying the test à la Forbes and Rigobon (2002) and Pesaran and Pick (2007), we examine whether the implementation of the APP has led to a significant increase in the correlations between non-fundamental or residual components of interest rates. This test is, from our point of view, an indirect way of knowing whether the QE has led to a significant

Figure 2: 10-Year Debt Return Index



decrease in sovereign bond yields. We also propose a complementary test centered on the impact of the QE on credit risk premiums by evaluating the possible deformations, after the implementation of the QE, of the sensitivity of the credit spreads to the premiums paid on the sovereign CDS.

The paper is organized as follows. Section 2 presents the practical terms for the QE program. Section 3 shows the main assumptions and results of the theoretical model of bond yields. Section 4 presents the different econometric methods and the construction of the correlation structural break test. Section 5 presents both the econometric and test results. Section 6 gives a general conclusion.

2 Asset Purchase Program (APP) and Public Sector Purchase Program (PSPP) in practice

The ECB's QE programs mainly correspond to the Public Sector Purchase Programme (PSPP) launched on 9 March 2015. It is part of a broader framework of the ECB's Assets Purchase Programs (APP) initiated internally with the Securities Markets Program (SMP, Table 1). Purchases made in the framework of PSPP mainly concern sovereign bonds (government bonds) but marginally on those of agencies and supranational organizations. Since June 2016, the QE programs also started focusing on investment-grade corporate bonds (Table 1).

The ECB has set several constraints on these purchasing programs: (1) Purchases are for securities with a maturity between 2 and 30 years; (2) Purchases may not relate to securities whose returns are below the deposit rates of the ECB (-0.2 percent by 03/2015 and -0.4 percent by 03/2016); (3) The ECB may not hold more than 25 percent of the securities from the same issue and no more than 33 of the same issuer.[3]

The proposed purchase amounts were 60 billion Euros per month in March 2015. It was raised to 80 billion in March 2016 and then to 70 billion in December 2016. The distribution of purchases

[3]In March 2015, the ECB's assets in Greece were, as a result of the aid program, in excess of the national debt limit of 33 percent. This explains why Greece was excluded since the beginning of ECB's purchase program.

between countries is based on the weight of each country in the capital of the ECB (Table 2). The important question here is to evaluate the effect of these purchases on the equilibrium of the bond markets and be able to compare the amounts purchased with the available quantity of securities in each market. These quantities are given by the country's debt stock at market value. They evolve with new issues and amortization of capital. Claeys et al. (2015) shows that these purchases are, for most countries, quite significant in terms of available securities. They show, for example, that the cumulative purchases by the ECB would saturate the constraints of the 25 percent by May 2017 for Germany and by January 2017 for Portugal. The constraint will already be saturated for Livia by Mai 2015, June 2015 for Cyprus, and November 2016 for Ireland. There would be more margin for Austria, Belgium, Ireland, France, Italy and Spain.

3 Theoretical background: an international portfolio model

In order to understand the formation of bond yields, we use the theoretical model proposed by Martin and Zhang (2016).

3.1 Hypothesis

It is a three-asset bond portfolio choice model: a risk-free monetary asset at rate r and two zero coupon bonds ($i = 1, 2$) of the same maturity including mainly interest rate risks. The sensitivity of the bond is denoted S thereafter. Optimal demand of bonds à la Markowitz can be written as follows

$$\alpha_1^* = \frac{(\mu_1 - r)}{r_a[\sigma_1^2 - (\frac{\sigma_{12}}{\sigma_2})^2]} - \frac{\sigma_{12}(\mu_2 - r)}{r_a\sigma_2^2[\sigma_1^2 - (\frac{\sigma_{12}}{\sigma_2})^2]} \quad (1)$$

$$\alpha_2^* = \frac{(\mu_2 - r)}{r_a[\sigma_2^2 - (\frac{\sigma_{12}}{\sigma_1})^2]} - \frac{\sigma_{12}(\mu_1 - r)}{r_a\sigma_1^2[\sigma_2^2 - (\frac{\sigma_{12}}{\sigma_1})^2]} \quad (2)$$

Where μ_1, μ_2, σ_1, σ_2 and σ_{12} represent the first and second order moments of bond yields over one period.

The supply-demand equilibrium conditions in each market are given by

$$\alpha_{1,t}^*[\mu_1(R_{1,t}), \mu_2(R_{2,t})]W_t = \varepsilon_{1,t}^S W_t \quad (3)$$

$$\alpha_{2,t}^*[\mu_1(R_{1,t}), \mu_2(R_{2,t})]W_t = \varepsilon_{2,t}^S W_t \quad (4)$$

Where $\varepsilon_{i,t}^S$ is the supply of bonds (in percentage of total wealth W_t), considered as a random process and a primary source of risk in the model. If we introduce a random European Central Bank demand ($\varepsilon_{i,t}^{ECB}$) to take into account the purchases of bonds through unconventional monetary policy, the net supply of bonds is given by

$$\Sigma_{1,t} = \varepsilon_{1,t}^S - \varepsilon_{1,t}^{ECB} \quad (5)$$

$$\Sigma_{2,t} = \varepsilon_{2,t}^S - \varepsilon_{2,t}^{ECB} \quad (6)$$

The bond demand of ECB decreases the net bond supply.

3.2 Equilibrium properties

Market equilibrium conditions give a 2-2 system with respect μ_1 and μ_2. Solving the system, we find the equilibrium expected return (rational expectations) of each obligation. Solutions are given by

$$\mu_1^* = r + \sigma_1^2 r_a \left(\Sigma_{1,t} + \frac{\sigma_{12}}{\sigma_1^2} \Sigma_{2,t} \right) \tag{7}$$

$$\mu_2^* = r + \sigma_2^2 r_a \left(\Sigma_{2,t} + \frac{\sigma_{12}}{\sigma_2^2} \Sigma_{1,t} \right) \tag{8}$$

The expected equilibrium returns are expressed as the risk-free rate plus a risk premium which depends crucially on the total bond supply, which measures the quantity of risks in the portfolio. The bond supply of country 2 has an impact on μ_1^* depending on the ratio covariance on variance ($\frac{\sigma_{12}}{\sigma_1^2}$) which plays as a beta factor.

By taking the definition of expected returns ($\mu_i = E_t(H_{i,t}) \simeq (1+S)R_{i,t} - SE_t(R_{i,t+1})$ with $H_{i,t} = \frac{P_{i,t+1} - P_{i,t}}{P_{i,t}}$), the solutions are obtained in form of actuarial rate of return on bonds, which are the true endogenous variables of the model.

$$R_{1,t}^* = \frac{1}{1+S} \left[r_t + SE_t(R_{1,t+1}) + S^2 V_t(R_{1,t+1}) r_a \left(\Sigma_{1,t} + \frac{Cov_t(R_{1,t+1}, R_{2,t+1})}{V_t(R_{1,t+1})} \Sigma_{2,t} \right) \right] \tag{9}$$

$$R_{2,t}^* = \frac{1}{1+S} \left[r_t + SE_t(R_{2,t+1}) + S^2 V_t(R_{2,t+1}) r_a \left(\Sigma_{2,t} + \frac{Cov_t(R_{1,t+1}, R_{2,t+1})}{V_t(R_{2,t+1})} \Sigma_{1,t} \right) \right] \tag{10}$$

The third term in bond rates appears as a one period risk premium with (net) supply effects depending on covariance regime. If $Cov_t(R_{1,t+1}, R_{2,t+1}) = 0$, we have

$$R_{i,t}^* = \frac{1}{1+S} \left[r_t + SE_t(R_{i,t+1}) + S^2 V_t(R_{i,t+1}) r_a (\Sigma_{i,t}) \right] \tag{11}$$

i.e. standard Euler's equation of long-term rate in a domestic term structure model according to the SHILLERian tradition. By resolving Euler's equation with respect to $R_{i,t}^*$ by forward substitutions on $R_{i,t+1}$ and by supposing S is constant in time, we find

$$\begin{aligned} R_{1,t}^* &= \tfrac{r_t}{1+S} + \tfrac{1}{1+S} \left[\textstyle\sum_{i=1}^{\infty} \left(\tfrac{S}{1+S}\right)^i E_t(r_{t+i}) \right] \\ &+ \tfrac{1}{1+S} \left[\textstyle\sum_{i=0}^{\infty} \left(\tfrac{S}{1+S}\right)^i E_t \left[S^2 V_{t+i}(R_{1,t+i+1}) r_a \left(\Sigma_{1,t+i} + \tfrac{Cov_{t+i}(R_{1,t+i+1}, R_{2,t+i+1})}{V_{t+i}(R_{1,t+i+1})} \Sigma_{2,t+i} \right) \right] \right] \end{aligned} \tag{12}$$

$$\begin{aligned} R_{2,t}^* &= \tfrac{r_t}{1+S} + \tfrac{1}{1+S} \left[\textstyle\sum_{i=1}^{\infty} \left(\tfrac{S}{1+S}\right)^i E_t(r_{t+i}) \right] \\ &+ \tfrac{1}{1+S} \left[\textstyle\sum_{i=0}^{\infty} \left(\tfrac{S}{1+S}\right)^i E_t \left[S^2 V_{t+i}(R_{2,t+i+1}) r_a \left(\Sigma_{2,t+i} + \tfrac{Cov_{t+i}(R_{1,t+i+1}, R_{2,t+i+1})}{V_{t+i}(R_{2,t+i+1})} \Sigma_{1,t+i} \right) \right] \right] \end{aligned} \tag{13}$$

The equilibrium rates of rational expectations include forecasts of all future equilibrium of the two bond markets. Covariance forecasts play an essential role.

Compared to the traditional properties of term structure interest rates theory, additional properties of our model are given by the presence of the term

$$\frac{Cov_{t+i}(R_{1,t+i+1}, R_{2,t+i+1})}{V_{t+i}(R_{1,t+i+1})} \Sigma_{2,t+i}$$

in equation (12) and its equivalent in equation (13). Based on this, we can find 3 following results.

Additional property 1: Impacts of anticipated covariance

Higher anticipated covariance leads to higher interest rates in both two countries; bond demands are lower because the hedging opportunities are lower as well. This means, in particular, that a contagion scenario between two markets, defined as a raising of both correlation and covariance between rates and with a scenario of future increases in long-term rates, is amplified. A “belief” that long rates will rise in both countries leads immediately (as soon as the portfolios are re-optimized) higher present rates.

We use the term "amplified" to describe the fact that the results of a contagion on interest rates, found in this mechanism of optimal portfolio choice, is to enhance the existing contagion. Conversely, scenario of end of the crisis with lower long-term rates in the country ($i = 1, 2$) and a decreasing covariance between markets is not amplified but on the contrary reduced. The scenario with higher covariance in the future reduces the possibilities of hedging, limits the bond demand and leads to rising rates in both countries.

We can also evaluate the nature of "amplified" in a scenario that covariance declines between two markets. In this case, a Flight-to-quality will favor one of the two markets. This scenario brings down rates in both two countries, therefore it’s amplified only in the market which is supposed to benefit from the Flight-to-quality mechanism. These results are summarized in Table 3.

Table 3: Impacts of covariance regime on long-term rates

Covariance regime	Ancipated evolution of rates	
Cov(R_1,R_2)$\nearrow$ Contagion or End of crisis	$R_1 \nearrow$,$R_2 \nearrow$ Contagion is amplified	$R_1 \searrow$,$R_2 \searrow$ End of crisis is reduced
Cov(R_1,R_2)$\searrow$ FTQ	$R_1 \rightarrow$ ou $\searrow$, $R_2 \nearrow$ Amplified in the country which benifits from FTQ	$R_1 \nearrow$, $R_2 \rightarrow$ ou $\nearrow$

Additional property 2: Impacts of news on public finance
Present and future conditions on bond supply (i.e. bond issue and debt amount) of each country have an impact on the bond market equilibrium of the other country. This impact fundamentally depends on the covariance regime anticipated by investors. For example, bad news about deficits and debt in Greece ($i = 2$) lead to higher interest rates in Greece ($i = 2$) but lower in Germany ($i = 1$) if the covariances are assumed negative. This mechanism becomes a component of the Flight-to-quality process.

The opposite case in a regime of positive covariance, the bad news about Greece’s public finances lead long-term rates to rise in both countries. The scenario of contagion is here again amplified.

Additional property 3: Impacts of ECB’s QE
The model also gives some lights on the impact of unconventional monetary policy on long-term rates in different countries. For example, in a regime of positive covariance, when the ECB buys (QE) or announces that it will buy (OMT and QE) Greek bonds ($i = 2$)[4], this leads to a decline of interest rates in both Greece and Germany ($i = 1$). On the contrary, this leads to higher rates in Germany if the covariances are supposed negative. In either case, this leads to a lower rate in Greece.

The willingness of the ECB, which aims to drive down long-term rates in the countries in difficulty, may therefore be reduced by the beliefs of investors. Remember that the variances here are exogenous, but the ambition of the ECB with the QE will trigger a joint process of falling rates. To achieve this, it would be right to make balanced purchases of bonds, which means not only in country 2 but also in country 1, in reality, on all the bond markets. For investors, the fact of knowing that purchases are joined and strongly correlated will clearly to increase the level of anticipated covariance,

[4]We consider Greece as an emblematic case of the countries in difficulty, even if since March 2015 this country is not eligible for purchases from the ECB (Section 2).

and thus enhance the efficiency of QE.

Finally, note that bond purchases by the ECB have an impact on the volatility premium and equilibrium long-term rates, which could be considered as a partial debt cancellation with an explicit modelling of the credit risk premium. The fact that the ECB puts on its balance sheet a portion of the debt of countries in difficulty means, for investors, a disappearance of the bonds purchased by the ECB , and therefore a lower potential volatility in portfolios. The impact on rates is analogous to a partial debt cancellation along with a disappearance of certain quantity of credit risks.

4 Empirical modelling

4.1 Data

The daily time series used in this paper are from January 2006 to September 2016 (Source: DataStream). As in many related litterature, we use the Return Yield ($R_{i,t}$) of 10-year government bonds [5] of seven major countries in the European Monetary Union including France, Germany, Italy, Portugal, Spain, Ireland and Greece; Vstoxx index (global factor); 3-month AAA Bond Rate (who represents the risk-free rate); as well as 5-year Credit Defaut Swaps (indicator of defaut risks).[6]

In the dynamics of interest rates, there exists obviously different phases. By applying the unit root test proposed by Lee and Strazicich (2003) on the daily Return Index of Greece, we are able to separate the time series into three sub-periods: pre-crisis (2006/01/01 to 2009/12/01), crisis (2009/12/01 to 2012/08/06), and post-OMT (2012/08/06 to 2016/09/09). We should notice that the two break dates 2009/12/01 and 2012/08/06 are very close to respectively the Downgrading of Greece sovereign bond and the Implementation of Outright Monetary Transaction[7].

4.2 Modelling choice

We pay attention to equations (7) and (8) of the theoretical model. It describes expected market equilibrium returns. By introducing a time index on the risk-free rates and both variances and covariances of yields, the equilibrium relation for country i is written

$$\mu^*_{i,t} = r_t + \sigma^2_{i,t} r_a \left(\Sigma_{i,t} + \frac{\sigma_{ij,t}}{\sigma^2_{i,t}} \Sigma_{j,t} \right) \tag{14}$$

With

$$\mu_{i,t} = \frac{E_t(P_{i,t+1}) - P_{i,t}}{P_{i,t}} \tag{15}$$

This relation assumes that the bond price $P_{i,t}$, or the associated yield $R_{i,t}$, is daily adjusted so that the expected return $\mu_{i,t}$ given the anticipated future price $E_t(P_{i,t+1})$ is consistent with the risk-free rate and the equilibrium risk premium. Since the absolute risk aversion coefficient (r_a) and the net bond supply ($\Sigma_{i,t}$, $\Sigma_{j,t}$) are not directly observable, so the equilibrium relation can be considered as a linear relation between the expected yield ($\mu_{i,t}$) the risk-free rate (r_t) and the variance ($\sigma^2_{i,t}$), and

[5] Most of the recent papers (Ehrmann and Fratzscher (2017), Silvapulle et al. (2016), Costantini et al. (2014), Gómez-Puig and Sosvilla-Rivero (2016)) use 10-year sovereign bond yields as benchmark. However, De Santis and Stein (2016) propose to use 5-year sovereign bond yield as a benchmark for the reason that aggregate demand is typically affected by long-term interest rates, and thereforete the correlation between long-term sovereign yields and the risk-free rate is a key economically relevant question.

[6] The market for CDS spreads used to measure the price of the credit risk is more liquid at 5-year maturity De Santis and Stein (2016).

[7] In a previous version of this paper, by using two times Zivot and Andrews (2002) test, we have obtained very similar results.

covariance ($\sigma^2_{ij,t}$) anticipated one-step-ahead.

To estimate this equilibrium relation from equations (7) and (8), it is necessary to do it, as for the estimation of CAPM models by replacing the expected returns by the observed daily returns in the sample. If the anticipations of investors especially on tomorrow's prices are rational, the difference between the two series should be a white noise. If these anticipations are not rational, there exists some inconvenience.

We use rather actuarial yields $R_{i,t}$, which also reflects the necessary adjustment on prices $P_{i,t}$, in order to respect the equilibrium relation. Due to the non-stationarity of actuarial rate series, finally the first differenced actuarial rates are explained by the first differenced risk-free rate, first differenced variances and covariance, and two first differenced control variables presented before, Vstoxx and CDS.

The second concern for this modelling is the definitions and estimations of variables and covariances anticipated by investors. A simple solution consists in estimating and evaluating the impact of the second order moments on the yield with a single step in the framework of a bivariate GARCH-in-mean model. We prefer to perform the estimations in two steps rather than a bivariate GARCH-in-mean model, because this auxiliary model is more manipulable and it provides actual out-of-sample risk predictions.

4.3 Model and estimation

In this empirical approach, we try to verify the results found in the theoretical model by applying two different methods: a two-step bivariate GARCH model and a two-step[8] rolling linear regression model.

4.3.1 Two-step GARCH model

In this two-step GARCH model, first step aims to forecast conditional variances and covariances which can be described as investors' anticipations of second order moments in our theoretical model. In the second step, estimations will be performed by using the forecasted values of both variances and covaraince from the first step, in order to understand the role of portfolio effects in the formation of sovereign bond yields.

Step 1: Investors' anticipations are simulated by using rolling window of classic bivariate DCC(1,1)-GARCH(1,1) model proposed by Engle (2002), and widely applied by for exemple Jones and Olson (2013) and Celık (2012).

$$H_t = D_t R_t D_t, where \quad D_t = Diag(\sqrt{h_{i,t}}) \tag{16}$$

where R_t is a 2×2 matrix of time-varying correlations. D_t is a 2×2 diagonal matrix of time-varying standard deviations of residual returns. The variances are obtained with univariate GARCH(1,1) processes. Specifically,

$$h_t = c + a\varepsilon^2_{t-1} + bh_{t-1} \tag{17}$$

One single sample of 500 days will give us a one-step-ahead prediction of conditional variance and covariance.[9]. By using a rolling window of 500 days, we obtain a serie of one-step-ahead forecasted values which can be considered as investors' anticipations of conditional variances and covariances.

[8]As already been discussed in many literatures, especially by Murphy and Topel (2002), this two-step procedure fails to account for the fact that imputed repressors are measured with sampling error, so hypothesis tests based on the estimated covariance matrix of the second-step estimator are biased, even in large sample. However we consider in our case, this sampling error is under control with a limited bias.

[9]For exemple, a sample from t to t+500 will be able to give a forecasting for t+501.

Step 2: In this step, we try to determine the role of portfolio effects in the formation of sovereign bond yields by applying a bivariate GARCH Model. We have two countries in each estimation. [10]For $i = 1$ and 2, the mean equations are presented as follows.

$$\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t} \quad (18)$$

With $R_{i,t}$ Acturial Rate (Yield to maturity) of each bond, $E_t(V_{i,t+1})$ anticipated variance, $E_t(Cov_{ij,t+1})$ anticipated covariance[11], $Vstoxx_{t-1}$ Vstoxx Index, r_t 3-month AAA Government Bond Rate. In accordance with the canonical contagion approach of Pesaran and Pick (2007), equation (16) tries to explain bond yields with global and specific factors. $Vstoxx_{t-1}$ denotes the implied volatility risks and also a global factor as discussed by Afonso et al. (2012), Arghyrou and Kontonikas (2012), and Metiu (2012). The specific factors are the Credit Default Swaps $CDS_{i,t}$ which denotes credit default risks, and both anticipated variances $E_t(V_{i,t+1})$, anticipated convariances $E_t(Cov_{ij,t+1})$ denote portfolio effects described in our theoretical model.

Under the hypothesis of conditional normal distribution of disturbances, the parameters of the model are estimated by the method of maximum likelihood. The log Likelihood function which should be optimized is given as follows

$$L_T(\theta) = -\frac{1}{2}\sum_{t=1}^{T}[ln[det(H_t(\theta))] + \varepsilon_t(\theta)' H_t(\theta)^{-1}\varepsilon_t(\theta)] \quad (19)$$

With $H_t = V(\epsilon_t/I_{t-1}) = \begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix}$ and $\varepsilon_t = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$

The matrix of variance-covariance is based on a diagonal VECH specification. Therefore, the conditional variance and covariance are expressed by

$$h_{ii,t} = c_{ii} + a_{ii}\varepsilon^2_{i,t-1} + b_{ii}h_{ii,t-1} \quad (20)$$

$$h_{ij,t} = c_{ij} + a_{ij}\varepsilon_{i,t-1}\varepsilon_{j,t-1} + b_{ij}h_{ij,t-1} \quad (21)$$

where c_{ij}, a_{ij} and b_{ij} are parameters and $\varepsilon_{i,t-1}$ is the vector of errors from the previous period. This specification supposes that the current conditional variances and covariances are determined by their own past and past shocks. Precisely, with algorithm Simplex and some guessing values, we stop the calculation at the fifteenth iteration. Next, with the values obtained from this pre-calculation, we use the method BHHH to estimate the GARCH model.

4.3.2 Two-step rolling linear regression

In this part, in order to estimate the evolution of amplifying factor discussed in section 3.2, we perform a rolling linear regression model.

Step 1: It is exactely the same method here to generate a serie of forecasted conditional variances and covariances as performed in ***Step 1*** in section 4.3.1. Therefore, we obtain a serie of one-step-ahead forecasted conditional variances and covariances which can be considered as investors' anticipations of these second order moments.

[10]In order to avoid the non stationary problem of the series, all the variables used in this model are first differenced. It's also the same case for the first step.

[11]Both anticipated variance and covariance simulate the investors' expectations as described in our theoretical model. We use a DCC-GARCH model with a rolling window of 500 daily data to forecast these two terms using one-step-ahead method.

Step 2: The linear model is same as the mean equation (18) presented above in the GARCH framework. For easy reading, we rewrite it here:

$$\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$$

To be more specific, in accordance with the forecasting of conditional variance and covariance with DCC-GARCH model, rolling window here is also 500 days. Each estimation of this linear model gives us several fitted coefficients, thus, the rolling window generates the dynamics of fitted coefficients which can be presented as sensibilities to the return yields.

4.4 Principals of correlation test

In this section, we test the hypotheses of structural changes of correlation coefficients across the pre-QE and post-QE periods. As pointed out by Forbes and Rigobon (2002), the estimation of the correlation coefficient is biased because of the existence of heteroscedasticity in the return of bond. More specifically, compared to the estimation over a stable period, the correlation coefficients are over estimated over a turmoil period. In our study, we consider the pre-QE period as the turmoil period and post-QE as the stable period. Because of the correlations are conditional and dynamic in our model, so we need to modify the adjustment formula of correlation coefficient proposed by Forbes and Rigobon into the following formula:

$$\rho^*_{ij,p} = \frac{\rho_{ij,p}}{\sqrt{1 + \delta(1 - \rho^2_{ij,p})}} \tag{22}$$

Where $\delta = \frac{h^{pre}}{s^{post}} - 1$ is the relative increase in the variance of the source country across pre-QE period and post-QE period. $\rho_{i,p}$ is the average of dynamic conditional correlations over period p, where $p = (pre, post)$, while *pre* and *post* indicate the pre-QE period and post-QE period. With the adjusted correlation coefficients, we apply the test proposed by Collins and Biekpe (2003) to detect the existence of structural breaks across pre-QE period and post-QE period.

The Student test is:

$$\begin{cases} H_0 : \rho^*_{post} = \rho^*_{pre} \\ H_1 : \rho^*_{post} > \rho^*_{pre} \end{cases}$$

Where ρ^*_{post} is the adjusted correlation coefficient over post-QE period and ρ^*_{pre} is the adjusted correlation coefficient over pre-QE period. The statistic of the student test applied by Collins and Biekpe is:

$$t = (\rho^*_{post} - \rho^*_{pre})\sqrt{\frac{n_{post} + n_{pre} - 4}{1 - (\rho^*_{post} - \rho^*_{pre})^2}} \tag{23}$$

where $t \sim T_{n_{post}+n_{pre}-4}$.

If we accept H_1, it means that the correlation coefficient across two periods has significantly increased over the post-QE period, that is an evidence of the impact of QE.

Finally, it should be noted that the test proposed here refers to residues, in other words the non-fundamental components of an explanatory model in accordance with the recommendations of Pesaran and Pick (2007), the global variables explain both two countries studied (Vstoxx, r, covariance) and country specific variables for each bond market (variance, CDS).

4.5 Sensitivity of spread to CDS

It is logically to expect that the ECB's massive purchases of sovereign bonds will, all other things being equal, raise the prices of bonds and thus reduce the credit risk premiums on bond yields and the spreads of bond yields. Under this assumption, interest rate spreads with Germany should be less sensitive to changes in premiums paid on sovereign CDSs. This represents market appreciation on credit risks. We will test this hypothesis by estimating the following model over different sub periods

$$Spread_{i,t} = \beta_{0,i} + \beta_{1,i}CDS_{i,t} + \epsilon_{i,t}. \tag{24}$$

With $spread_{i,t}$: spread of country i compared to Germany; $CDS_{i,t}$ premiums paid on CDS[12]. The model will be estimated over a Pre-QE period and a Post-QE period.

5 Empirical results

5.1 Dynamics of price and yields and patterns of anticipated variances and covariances

The patterns of variance and covariance evolutions anticipated by investors (Appendix B and C) are inextricably related to the dynamics of sovereign bond prices and the associated actuarial rates (Figures 1 and 2). We should recall that the important phases of the markets dynamics have implications in terms of covariances and volatilities.

The first bond price collapse took place on Oct. 16, 2009 accompanying the beginning of fiscal crisis in Greece. Only the Greek obligations are affected (Figures 1 and 2). The downgrade of Greece debt by Moody's on 8 December 2009 has amplified the collapse of the Greek bond market. The first effects of the contagion occurred in March 2010 on the Irish, Spanish and Portuguese markets. On the contrary, the German and French markets remain rising. According to our estimations, it is also in March 2010 that a very first elevation of anticipated volatility occurs. This first thrill touches the seven bond markets analysed.

The contagion reaches a historical level at the end of 2010 where for the very first time, the bond markets of 7 countries start suffering significantly and simultaneously downward movements (Figure 1). The short-term downward trend for the German and French markets restart to rise from March 2011 in a low volatility context. Actually our estimations show not only a decrease in anticipated volatility in these two markets but also a pronounced fall in covariances between German, French and the other markets. It is clearly that the beginning of the Flight-to-quality phenomenon is in favor of the two countries considered as the healthiest, where credit risk is lower. This particular phase is truly the first nodal point in the bond market trajectory during the sovereign debt crisis. The second nodal point appears in the year 2011, precisely on December 8th, when the ECB announces the implementation of an exceptional 3-year refinancing program for euro area banks (LTRO) and Mario Draghi implies that the ECB will not make massive purchases of sovereign bonds. Dec. 8, 2011 represents a peak of anticipated volatility for the German and French markets. Since this date, Italy, Spain and Ireland joined Germany and France and start to have a stable phase in terms of obligation yields. For these three countries, the anticipated covariances with Germany and France step out of their lowest level and rebound gradually. This is the symbol of the end of the crisis. Portugal joins rapidly in this group of countries in early 2012. It is not until 26 July 2012, when Mario Draghi gives "whatever it takes speech" and announces the implementation of the OMT in the euro area, that Greece steps into a new post-crisis phase.

[12] The CDS premium is purged of the effects related to the overall uncertainty variable $Vstoxx$ as in De Santis and Stein (2016).

The anticipated variances of the 10-year bond yield variations show strong disparities in the observed average level. It ranges from 0.04 for Germany to 2.5 for Greece. The evolution patterns over time present more similarities. In all seven markets, the volatility anticipated by investors truly starts to rise from the beginning of 2010. However, the profiles are different in the periphery countries of the euro area. The volatility rises significantly from early 2010 and reaches the peak at the end of 2011. Precisely, the date of this volatility peak is 8 Dec 2011. It is associated with the decision that the ECB will grant a 3-year special financing for banks in the euro area (LTRO). This event, which is rather favorable for the resolution of the sovereign debt crisis, is counterbalanced by a declaration of Mario Draghi claiming that the ECB did not intend to carry out massive purchases of sovereign bonds. This date 8 Dec 2011 is sort of a break point in the history of the interest rate trajectory in the euro area.

5.2 Two-step GARCH results

The results of 21 bivariate model estimations are shown in Tables 9 to 15. Concerning the one-step-ahead forecasts of variances and covariances, it comes out quite clearly that covariances are playing a more significant and systematic role in the dynamics of sovereign rates. The estimated parameters have most often the expected positive signs. The effects are generally more present in the German and French markets than in the euro zone periphery markets. The parameters associated with the covariance often show a U-shape pattern with lower values over the crisis period. We observe for example the following sequence. For the impacts of the Germany-Portugal covariance on German yields: 1.62 (pre-crisis), 0.48 (crisis), 1.86 (post-OMT) and 0.90 (crisis), 4.84 (post-OMT) for the impacts of France-Ireland covariance on French yields. It is generally found that, in terms of covariance impacts on evolution of sovereign bond yields, French yields are twice more sensible than those of German yields. As for the one-step-ahead forecasts of variances, their impacts are higher at the end of sample which means over the post-OMT period, particularly in German and French markets. The sensitivity of first differenced yield to variance variation is 2.97 for Germany (Germany-France in Table 9) and 1.82 for France (France-Italy in Table 11). It should be noted that the same coefficients may vary widely from one estimation to another depending on different selected pairs, and therefore it depends on the covariances included in the regression model.

The variable Vstoxx reflects an overall uncertainty that should have impacts on yields of risky assets in general, so as well as on sovereign bonds. This mechanism has been well supported by our estimates with generally positive coefficients for this variable. The obtained coefficients are again higher for Germany (0.013) and France (0.021) as well as Ireland (0.014). The risk-free rate shows also the expected positive sign. Throughout the whole period, the estimated coefficients range from 0.12 to 0.20 for Germany, France and Greece. This coefficient is never significant for Ireland. In terms of the influence of CDS (cleaned by Vstoxx), we get similar results to those obtained with covariances. The fitted coefficients are higher and more significant for Germany and France, besides, with slightly higher values over post-OMT period. The coefficients of CDS are also higher in the Ireland bond market according to regression results. Finally we note that the parameters of variance-covariance H_t of VECH model are almost always significant at the 5% level, with the usual positive signs.

5.3 Two-step rolling regression results

We examine next the patterns of coefficient evolutions associated with variances and covariances which obtained from the 500-day rolling window regressions. The results are given in Appendix E. For each country, the curve shows the estimated coefficient ($\hat{\beta}_{1,i}$) associated with changes in variances described in equation (18) which explains the first differenced yields. There are as many coefficients as estimated pairs, that is to say 6 for each country. As emphasized above, the estimated coefficients

($\hat{\beta}_{1,i}$) may be affected by the selected pairs and therefore by the selected covariances in equation (18). For each country, the graphic reports also rolling estimates of coefficients ($\hat{\beta}_{2,i}$) associated with different variations of covariances. Again, there are as many coefficients as pairs of covariances. We should also note that all coefficient estimates ($\hat{\beta}_{1,i}$ and $\hat{\beta}_{2,i}$) are modulated by taking into account the uncertainty of the estimates, that is to say the estimated standard deviation ($\hat{\sigma}_{\hat{\beta}_i}$). Each graphic reports the central value of the estimate, a lower bond ($\hat{\beta}_i - 1.96\hat{\sigma}_{\hat{\beta}_i}$) and an upper bond ($\hat{\beta}_i + 1.96\hat{\sigma}_{\hat{\beta}_i}$) for this estimate as well. A coefficient β_i will be considered significant at 5 percent level if neither lower or higher bonds of the estimate cross zero ($\hat{\beta}_i = 0$).

In order to qualify the different phases of our sample between pre-crisis, crisis and post-OMT, we adopt the following principle. A coefficient $\hat{\beta}_i$ is considered as being specific to a particular phase if the majority of dates included in the estimations, that is to say more than 250 days, are on this historic range. With this principle, the phases associated with the coefficients $\hat{\beta}$ correspond to the historical ranges with a lag of 251 days, which in practice corresponds to a lag of 11 months. Thus, from the point of view of coefficients $\hat{\beta}$ associated with covariances and variances anticipated by investors, the crisis period begins from 01/11/2010 and the post-OMT period begins from 04/08/2013.

To be more specific, concerning coefficients $\hat{\beta}_2$ associated with covariances, these rolling windows make it possible to give a much more precise pattern of estimates than the results provided by the sub-period estimations (Tables 9 to 15) where a U-shape emerged, especially for Germany and France.

We want to highlight the following results. The pattern of coefficients $\hat{\beta}_2$ with U-shape is globally confirmed in Germany and France. To a lesser extent, it's found as well as in Portugal (covariances with Italy, France and Spain) and Spain (covariances with Germany, Ireland and France). In some cases, the U-shape curve during the crisis period is accompanied by a non-significance of the coefficient β, which become sometimes even negative. Italy, Ireland and Greece show atypical profiles where bond yields become sensitive to covariances only from the beginning of post-OMT period: covariances of Italy with Germany, Ireland, and France; covariances of Ireland with Italy, Spain, and France; covariance of Greece with Ireland. Again, the negative impacts of covariances on long-term rates should be highlighted: covariance between Italy and Portugal on Italian rates; covariance between Greece and Germany on Greek rates.

Overall, these results show that bond portfolio mechanisms have clearly played a role between Germany, France, Portugal and Spain during pre-crisis period before becoming less important or disappearing during the crisis and again reappear in the post-OMT period. For the second group of countries, Italy, Ireland and, to a lesser extent, Greece, the portfolio mechanisms only appear in the post-OMT phase.

Furthermore, it is possible to quantify the effects of first differenced anticipated covariance on the formation of interest rates. For illustrative purposes, we can evaluate the contribution of the decrease in bond yield covariances between Germany and France and other European countries on the trajectory of German and French rates during the period of sovereign debt crisis. The tables below summarize the cumulative effects for German and French rates as shown in the graphics in Appendix E with the means of the coefficients $\hat{\beta}_2$ on the first phase of the estimations.

Table 4: Example of covariance effects on German market

Germany			
Pair with	Cumulative ΔCov	$\hat{\beta}_2$ mean	Cumulative effects
Italy	-0.05	7	-0.35
Portugal	-0.06	2.5	-0.15
Spain	-0.06	7	-0.42
Ireland	-0.06	2.5	-0.15
Greece	-0.12	2	-0.24
			Total effects: -1.31

Table 5: Example of covariance effects on French market

France			
Pair with	Cumulative ΔCov	$\hat{\beta}_2$ mean	Cumulative effects
Italy	-0.06	15	-0.90
Portugal	-0.06	10	-0.60
Spain	-0.06	13	-0.78
Ireland	-0.08	5	-0.40
Greece	-0.07	7	-0.49
			Total effects: -2.81

The cumulative declines in covariance between German and French yields with those of the other five countries are very similar. On the other hand, the sensitivity of yields to covariances is significantly higher on French market where the coefficients vary between 5 (covariance with Ireland) and 15 (covariance with Italy), and most of the time, they are twice as big as the coefficients $\hat{\beta}_2$ associated with German yields.

Overall, being aware of the transitory nature of the covariance effects on the yields due to the estimation of the model in variation, we estimate that the decrease in covariances at the beginning of the crisis period (beginning of 2011) potentially contributed to the decrease in French and German yields, respectively 131 and 281 bps. Finally, we have some evidence supporting the mechanism of an amplified Flight-to-quality process led by anticipated covariances and portfolio effects as presented in Table 3.

We can finally emphasize that, contrary to post-OMT, the phase begins 03/11/2015 with the implementation of the QE by the ECB is associated with a sensitive increase in the German and French yields and those of the other five countries. As in the same period, the sensitivity of bond yields to the covariances rises as well. We deduce that the portfolios effects reduce the process of declines in German and French bond yields. This time we illustrate a process of falling yields and exit out of the crisis to be reduced by the covariance and portfolio effects presented in Table 3.

Finally, we examine the effects of anticipated variances on the yield variations as they are provided by the two-step rolling linear regression estimations. With the exception of France and Greece, it is always possible to identify at least a sub-period where the coefficient $\hat{\beta}_1$ is significantly different from zero and being positive. Unlike the results obtained on covariances, the periods with significant coefficients generally do not cover the three phases, pre-crisis, crisis and post-OMT. Actually, the $\hat{\beta}_1$ coefficients can be only significant in an occasional way over a short period.

As for Germany, several estimations agree on a coefficient $\hat{\beta}_1$ close to 5, over a short period of one year beginning from mid-2015. A similar result is obtained for Ireland with a coefficient close to 8. As for Italy and Portugal, coefficients are also significant from mid-2015 with some values close to 1 and 0.5 respectively. Finally, for Spain, there is a U-shape pattern for the coefficient $\hat{\beta}_1$ with the following values: close to 3 till 2012, 0 till mid-2015 and 1 afterwards.

5.4 Higher correlations between yields since APP ?

Correlations between the residuals of first differenced bond yields are reported in Appendix F. It shows clearly that beginning from March 2015, there is a very strong rebound in dynamic conditional correlations estimated by the bivariate GARCH model. It is therefore the "visible hand" of the APP appears here. However, Table 4 which reports the statistics of the T test à la Forbes and Rigobon shows that it is not possible to conclude that all correlations are higher after the APP as a general result.

Table 6: Results of correlation structural break tests à la Forbes and Rigobon

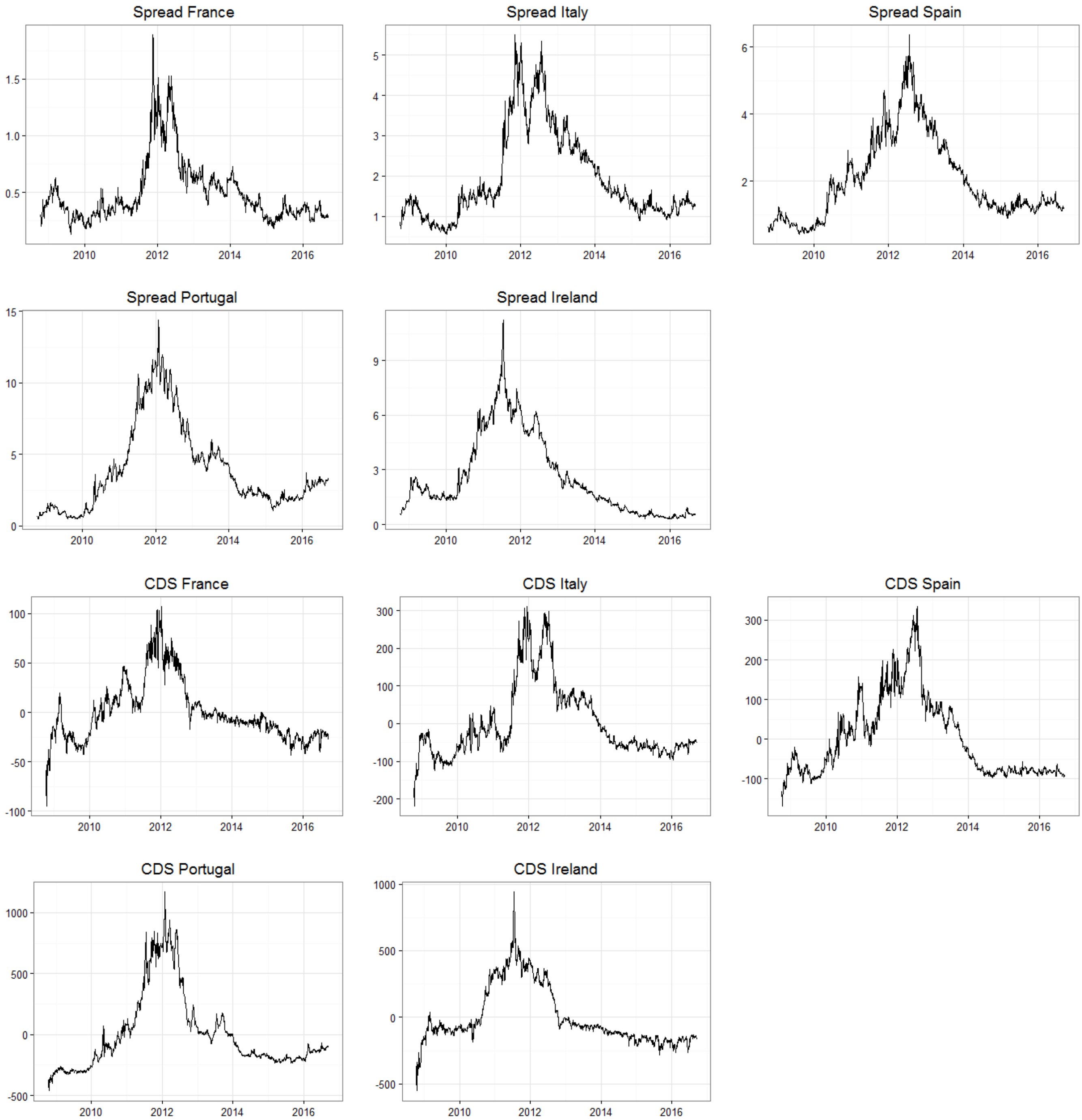
Country Pair	T-stat	Sig.	Country Pair	T-stat	Sig.
Germany-France	-1.250	0.211	France-Germany	-1.207	0.227
Germany-Italy	0.089	0.928	Italy-Germany	0.118	0.905
Germany-Portugal	0.028	0.977	Portugal-Germany	0.028	0.977
Germany-Spain	-0.889	0.373	Spain-Germany	-0.923	0.355
Germany-Ireland	0.004	0.996	Ireland-Germany	0.008	0.993
Germany-Greece	-0.083	0.933	Greece-Germany	0.168	0.866
France-Italy	-0.325	0.744	Italy-France	-0.505	0.613
France-Portugal	**-2.003**	**0.045**	Portugal-France	**-2.005**	**0.045**
France-Spain	-1.126	0.260	Spain-France	-1.266	0.205
France-Ireland	0.406	0.684	Ireland-France	0.814	0.415
France-Greece	-0.136	0.891	Greece-France	-0.202	0.839
Italy-Portugal	-0.589	0.555	Portugal-Italy	-0.451	0.651
Italy-Spain	**-1.777**	**0.075**	Spain-Italy	-1.434	0.151
Italy-Ireland	0.054	0.956	Ireland-Italy	0.073	0.941
Italy-Greece	1.425	0.154	Greece-Italy	1.421	0.155
Portugal-Spain	-0.375	0.707	Spain-Portugal	-0.393	0.694
Portugal-Ireland	0.028	0.977	Ireland-Portugal	0.058	0.953
Portugal-Greece	**-1.902**	**0.057**	Greece-Portugal	**-2.308**	**0.021**
Spain-Ireland	0.595	0.551	Ireland-Spain	1.095	0.273
Spain-Greece	-0.857	0.391	Greece-Spain	-0.977	0.328
Ireland-Greece	0.272	0.785	Greece-Ireland	0.186	0.852

5.5 Lower sensitivity of Spread to CDS since APP ?

The following charts reproduce the sovereign bond spreads with Germany and CDSs over the period 2008-2016. It suggests a strong correlation between spreads and CDSs. The table below shows the results of bond spread regressions on CDSs. They clearly show that the implementation of QE in March 2015 has greatly reduced the spread sensitivity to CDS and thus artificially crushed the credit risk premiums weighing on bond yields. The spread sensitivity to CDS decreases by half in Italy and Spain. It becomes negative for France and almost null for Ireland. Only Portugal, where there is no change in the sensitivity to credit risk, derogates from the rule[13].

[13] As for France, Italy and Ireland, CDS continued to decline over the QE period (Figure 3), we are led to believe that interest rate spreads would have been even lower without the implemetation of the QE from March 2015. We can

Figure 3: CDSs and Spreads



also interrogate both the true exogenity of CDS in this model and the potential impact of QE on the CDS evolution patterns. These questions may be the subject of future research.

Table 7: Sensitivities of spreads to CDSs over different periods

Regression model[14]: $Spread_{i,t} = \beta_{0,i} + \beta_{1,i} CDS_{i,t} + \epsilon_{i,t}$

Country	Period	$\bar{R}^2$	β_1	T-stat	Sig.
France	Full sample	0.6112	0.0071	57.0186	0.0000
	Before QE	0.5882	0.0073	48.9736	0.0000
	During QE	0.3471	-0.0049	-14.4181	0.0000
Italy	Full sample	0.9237	0.0109	158.2638	0.0000
	Before QE	0.9186	0.0109	137.6247	0.0000
	During QE	0.2588	0.0059	11.6981	0.0000
Spain	Full sample	0.8528	0.0115	109.4617	0.0000
	Before QE	0.8490	0.0120	97.1619	0.0000
	During QE	0.0842	0.0067	6.0651	0.0000
Portugal	Full sample	0.9560	0.0093	212.1261	0.0000
	Before QE	0.9543	0.0093	187.3026	0.0000
	During QE	0.8682	0.0133	50.6342	0.0000
Ireland	Full sample	0.9439	0.0096	186.6597	0.0000
	Before QE	0.9441	0.0093	168.3740	0.0000
	During QE	0.0101	-0.0004	-2.2300	0.0263

6 Conclusion

This paper tries to analyze the impact of the ECB's APP on the European bond market equilibrium and particularly on its contribution to the decline in sovereign rates. Therefore, we use a conceptual framework to understand the formation of long-term interest rates over the periods of pre-crisis and post-crisis with the implementation of the ECB's QE. We take the framework of portfolio theory to examine the specific role of short-term risks, perceived by investors, in the formation of sovereign bond yields. Our study is different from most of the recent papers which focuses on the impact of credit risk, on changes in CDS premiums, on the formation of interest rates and on the measurement of the phenomenon of contagion and Flight-to-quality between bond markets (De Santis and Stein (2016), Metiu (2012)), Afonso et al. (2012), Arghyrou and Kontonikas (2012), Pesaran and Pick (2007), Krishnamurthy and Vissing-Jorgensen (2011), Silvapulle et al. (2016)).

The theoretical model proposes a portfolio framework with three assets: a risk-free monetary rate and two sovereign bonds including default risks and volatility risks when the holding period is less than the maturity of the bond. The market equilibrium of each country results from the global demand for obligations and the supply of bonds, that is to say the available bond stock. The demand is given by optimal portfolio choices and purchase programs by the ECB in the context of Quantitative Easing. The bond purchases of ECB actually reduce the net bond supply and limit the volatility risks in the international monetary and bond portfolios. The anticipated variances and covariances play a key role in the future trajectories of long-term equilibrium sovereign bond rates.

In particular, the anticipated covariances constitute a channel likely capable of amplifying the mechanisms of contagion and Flight-to-quality between markets. A downgrade of public finance in a

[14] Spreads are calculated by the difference between the 10-year government bond yield of the country studied and that of Germany. Variable CDS_t takes residual values ($\hat{u}_{i,t}$) from following auxiliary regression: $CDS_{i,t} = \beta_{0,i} + \beta_{1,i} Vstoxx + u_{i,t}$

country leading to new bond issues not only raises rates in this country but also in neighbor countries if the anticipated covariances are positive (amplified contagion). The bad news about public finances, on the contrary, decrease rates in neighbor countries if the anticipated covariances are negative (amplified Flight-to-quality). Our theoretical model also suggests that the bond purchases programs of the ECB in the framework of Quantitative Easing should not be targeted to a single market in difficulty but rather on several diversified markets in order to trigger a joint decreasing rate process.

The empirical approach is based on daily data for the period over January 2006 to September 2016 integrated in the first step a bivariate DCC-GARCH model, and estimated by 500-day rolling windows in order to simulate the series of variances and covariances anticipated by the investors. In the second step, bivariate GARCH models with a VECH specification for the matrix of variance-covariance matrix are proposed, and estimations are performed on 21 country pairs over both the whole period October 2008 to September 2016 and three sub-periods qualified as pre-crisis, crisis, and post-OMT. All variables used in the models are first differenced variables. The mean equation explains the bond yields by the variances and covariances anticipated by investors, the short-term interest rate of euro area issuers rated AAA, the VSTOXX index and finally the premium paid on CDS as an essential determinant of the default risk premium required on sovereign bonds. In the third step, a linear version of this model, without ARCH effects, is estimated by 500-day rolling windows to analyze as well as the possible dynamics of the coefficients by taking into account the matrix of variance-covariance anticipated by investors.

The estimates over the whole period, sub-periods and, more importantly, estimates by using rolling windows show that the bond markets don't evolve solely as a result of changes in default risks and CDS premiums. The bond yields of the seven European countries are also sensitive to the volatility risks of covariances implied in bond portfolios. All the results can be refined as follows.

(i) German and French bond yields are more sensitive to the volatility risks of covariances than those of periphery countries. **(ii)** The covariances effects are stronger than those of variances, which are often present in occasional way. **(iii)** The decrease in covariance between the German and French markets at the beginning of the crisis period significantly reduced the risk premiums required by investors and contributed to the decrease in yields by 131 bps for Germany and 281 bps for France. **(iv)** Overall, the short-term risk premium intensity on portfolios and bond yields declines sharply during the crisis, and reappear later over the post-OMT and post-QE period. Everything happens as if the mechanism of international bond portfolio allocation had ceased during the sovereign debt crisis and then reappeared. These results are consistent with other recent studies (De Santis and Stein (2016), Ehrmann and Fratzscher (2017)) highlighting the hypothesis of possible fragmentation on the European bond markets during the crisis.

We note as well as that the implementation of the ECB's QE, actual purchases from March 2015 has contributed to a process of returning to normal or defragmentation of bond markets. According to our evaluations this defragmentation was initiated before the implementation of the QE. It only has been strengthened by the APP. Finally according to the test à la Forbes and Rigobon (2002), it seems difficult to affirm that QE programs have led a significant increase in correlations between bond markets, simply because the correlations were already high before the implementation of QE. The complementary tests of the regression of CDS on spreads show that the QE significantly reduced their sensitiviy to credit risk premium.

By construction, our dynamic econometric model estimated in first difference does not allow to propose an absolute quantification of the QE's impact on the bond rates of each country. However, the combination of results obtained from econometric estimates, in particular the rolling model, the conditonal correlation test à la Forbes and Rigobon, and CDS spread sensitivity tests, suggests that the impact of QE on the bond market equilibrium is not as strong as expected. Therefore, the probable cessation of QE from 2018 would not, from this point of view, lead a violent rise in interest rates.

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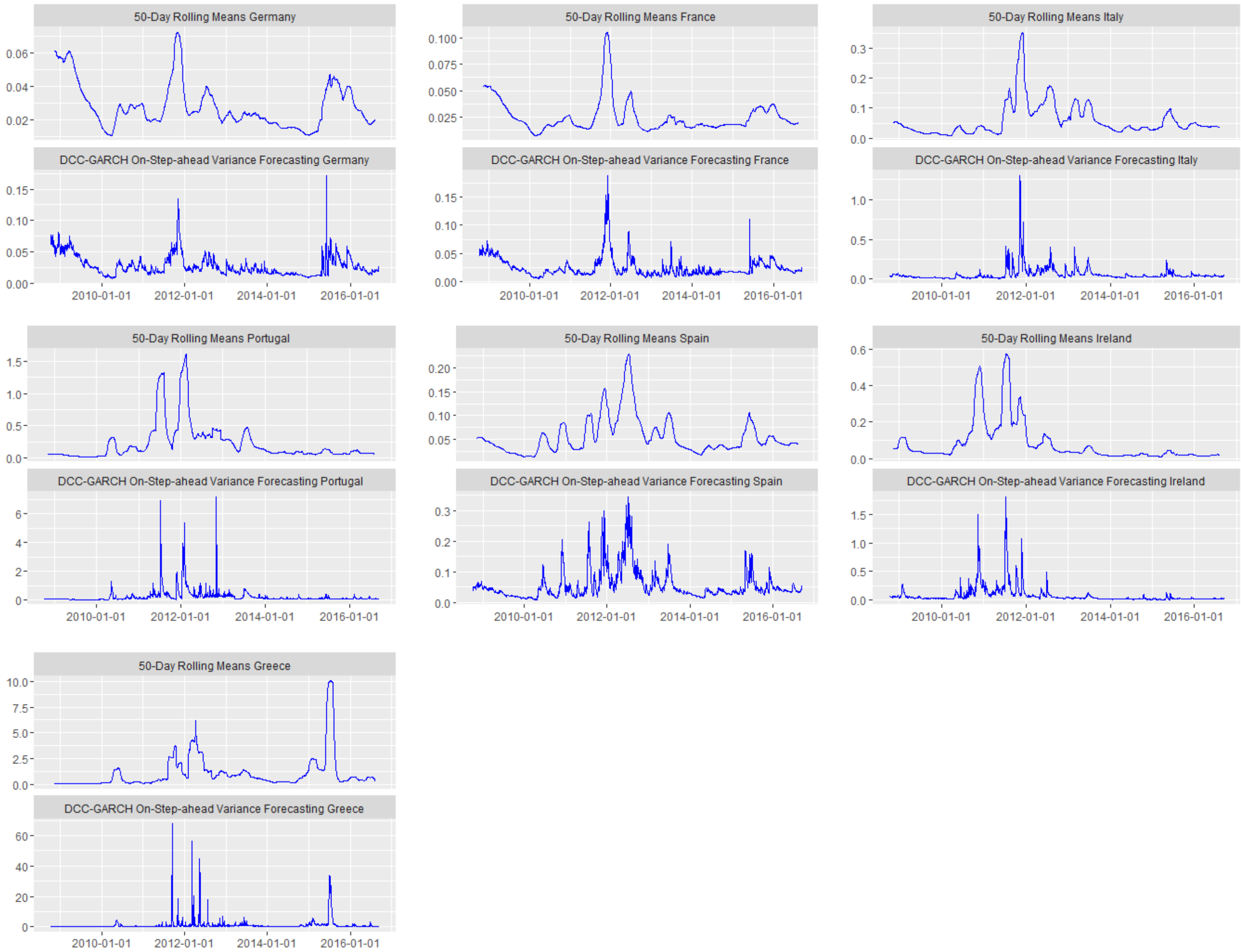
Appendix A Descriptive Statistics

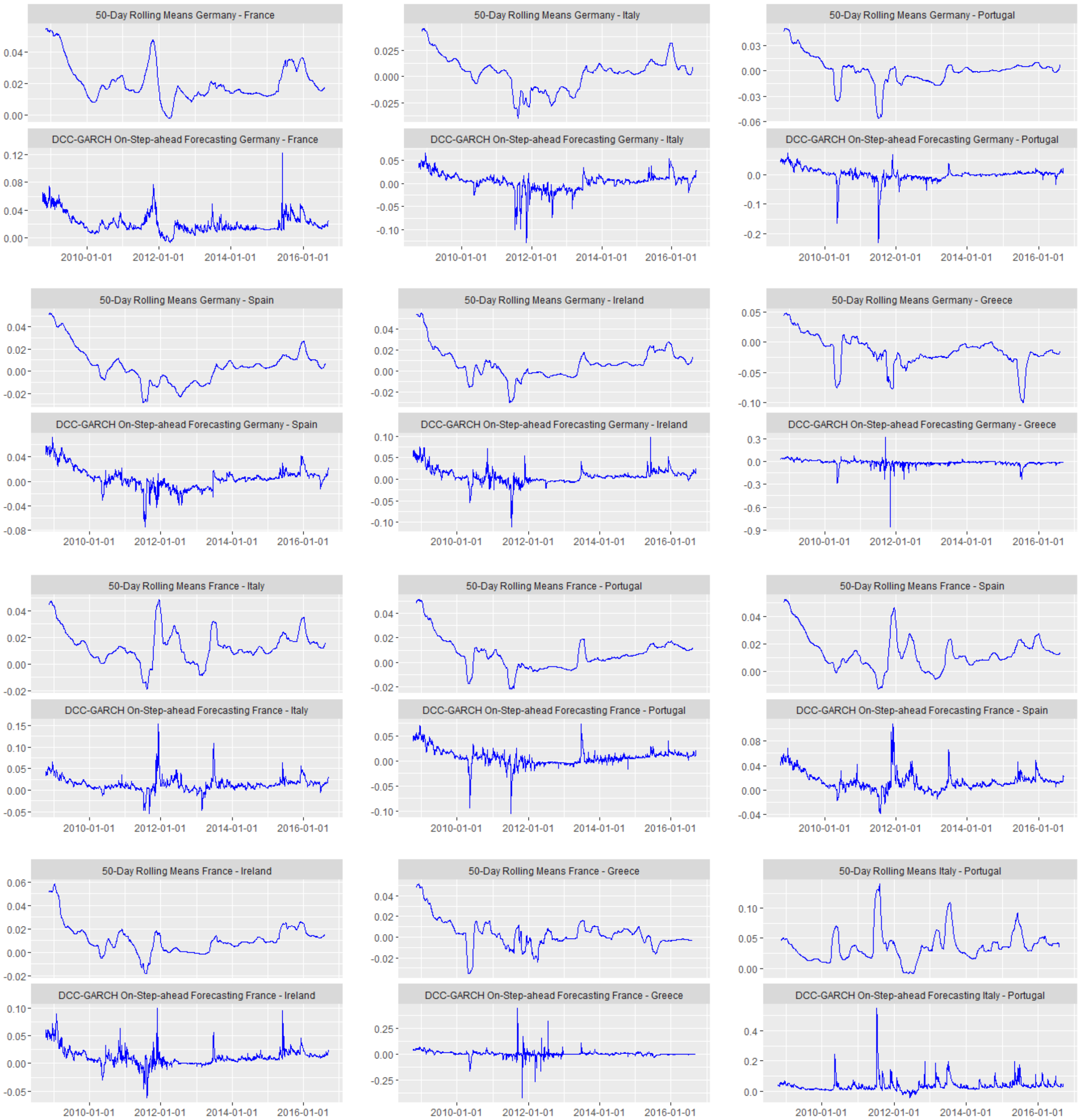
Table 8: Descriptive statistics

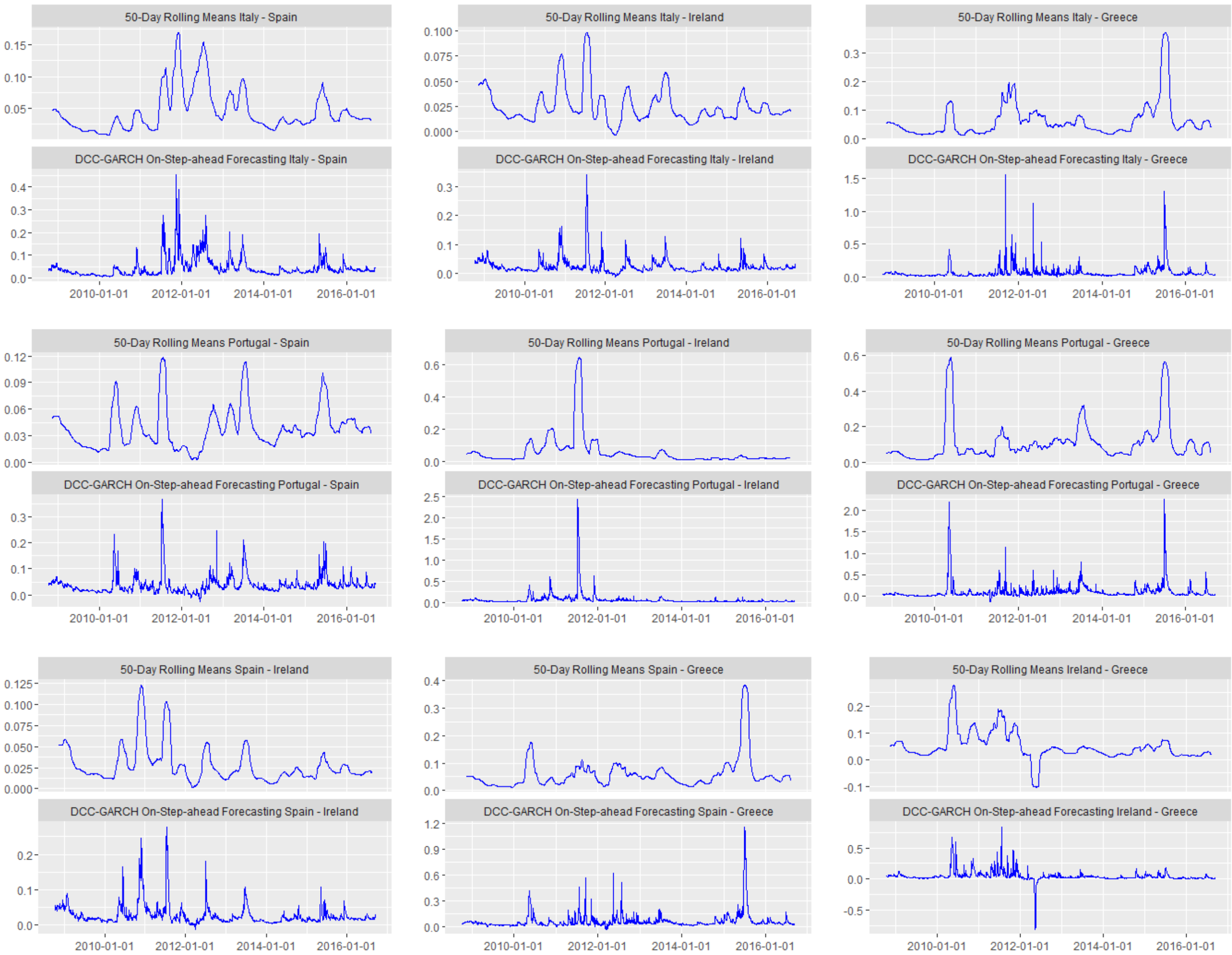
Statistic	N	Mean	SD	Min	Max
German	2,070	1.826	1.078	−0.187	4.117
Spain	2,070	3.858	1.529	0.983	7.590
Ireland	2,070	4.408	2.779	0.338	13.895
Greece	2,070	11.645	7.564	4.393	48.602
France	2,070	2.323	1.105	0.100	4.346
Portugal	2,070	5.752	3.110	1.368	16.211
Italy	2,070	3.772	1.434	1.049	7.288
AAA	2,070	0.230	0.573	−0.682	3.637
CDSES	2,070	155.339	100.322	45.420	492.070
CDSFR	2,070	49.722	32.422	14.006	171.560
CDSIR	2,070	228.386	226.935	29.280	1,191.158
CDSDE	2,070	25.017	16.671	6.640	92.500
CDSGR	2,070	9,209.199	6,805.436	66.500	14,911.740
CDSIT	2,070	163.326	99.781	48.000	498.660
CDSPT	2,070	346.660	314.960	37.000	1,521.450
VSTOXX	2,070	26.048	9.553	12.713	87.513

Appendix B One-step-ahead Variance Forecasts



Appendix C One-step-ahead Covariance Forecasts





50-Day Rolling Means Italy - Spain
DCC-GARCH On-Step-ahead Forecasting Italy - Spain
50-Day Rolling Means Italy - Ireland
DCC-GARCH On-Step-ahead Forecasting Italy - Ireland
50-Day Rolling Means Italy - Greece
DCC-GARCH On-Step-ahead Forecasting Italy - Greece
50-Day Rolling Means Portugal - Spain
DCC-GARCH On-Step-ahead Forecasting Portugal - Spain
50-Day Rolling Means Portugal - Ireland
DCC-GARCH On-Step-ahead Forecasting Portugal - Ireland
50-Day Rolling Means Portugal - Greece
DCC-GARCH On-Step-ahead Forecasting Portugal - Greece
50-Day Rolling Means Spain - Ireland
DCC-GARCH On-Step-ahead Forecasting Spain - Ireland
50-Day Rolling Means Spain - Greece
DCC-GARCH On-Step-ahead Forecasting Spain - Greece
50-Day Rolling Means Ireland - Greece
DCC-GARCH On-Step-ahead Forecasting Ireland - Greece
2010-01-01
2012-01-01
2014-01-01
2016-01-01

Appendix D Two-step GARCH Models

Table 9: Parameter estimates of the GARCH models

Mean equation: $\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$

	Germany-France				Germany-Italy				Germany-Portugal			
Coefficient	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT
β_{01}	**-0.003**		**0.008**	**-0.005**	**-0.003**		**0.006**	**-0.006**	**-0.003**	-0.003	0.003	**-0.005**
	(0.015)		**(0.000)**	**(0.002)**	**(0.006)**		**(0.012)**	**(0.000)**	**(0.006)**	(0.375)	(0.282)	**(0.001)**
β_{02}	-0.001		**0.051**	**-0.010**	**-0.007**		**-0.006**	**-0.008**	**-0.007**	-0.006	0.002	**-0.010**
	(0.775)		**(0.000)**	**(0.001)**	**(0.000)**		**(0.005)**	**(0.000)**	**(0.000)**	(0.112)	(0.403)	**(0.000)**
β_{11}	0.584		**-2.332**	**2.976**	0.010		**-2.637**	0.413	0.116	**-2.837**	**-2.203**	**0.496**
	(0.121)		**(0.020)**	**(0.000)**	(0.953)		**(0.003)**	(0.128)	(0.491)	**(0.005)**	**(0.000)**	**(0.005)**
β_{12}	**-2.669**		-0.220	-0.696	0.035		0.065	**0.210**	0.006	0.715	0.000	0.010
	(0.000)		(0.913)	(0.484)	(0.328)		(0.222)	**(0.011)**	(0.456)	(0.479)	(1.00)	(0.189)
β_{21}	0.139		0.274	-0.975	**0.266**		**-2.191**	**1.868**	**0.704**	**1.629**	**0.487**	**1.879**
	(0.795)		(0.842)	(0.111)	**(0.039)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.044)**	**(0.000)**	**(0.000)**
β_{22}	**3.464**		**-4.812**	**3.609**	**1.197**		0.346	**2.28**	**0.430**	-0.270	0.021	**1.319**
	(0.000)		**(0.096)**	**(0.004)**	**(0.000)**		(0.206)	**(0.000)**	**(0.092)**	(0.774)	(0.96)	**(0.012)**
β_{31}	**0.005**		**0.011**	**0.013**	**0.008**		**0.013**	**0.016**	**0.005**	**-0.005**	**0.008**	**0.013**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.001)**	**(0.000)**	**(0.000)**
β_{32}	**0.004**		**0.006**	**0.021**	**-0.010**		**-0.010**	**-0.011**	**0.003**	-0.001	**0.003**	**0.008**
	(0.000)		**(0.017)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.800)	**(0.026)**	**(0.000)**
β_{41}	**0.122**		**-0.148**	0.054	0.070		**-0.119**	-0.072	**0.106**	**0.161**	-0.089	0.055
	(0.005)		**(0.003)**	(0.595)	(0.122)		**(0.067)**	(0.488)	**(0.025)**	**(0.021)**	(0.248)	(0.620)
β_{42}	**0.201**		-0.178	-0.139	**0.188**		0.078	-0.135	**0.125**	**0.159**	-0.089	0.098
	(0.023)		(0.329)	(0.453)	**(0.000)**		(0.332)	(0.105)	**(0.012)**	**(0.086)**	(0.371)	(0.424)
β_{51}	**0.004**		**0.005**	**0.006**	**0.006**		**0.006**	**0.007**	**0.003**	-0.001	**0.003**	**0.006**
	(0.000)		**(0.000)**	**(0.003)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.540)	**(0.000)**	**(0.001)**
β_{52}	**0.002**		**0.002**	**0.010**	**-0.003**		**-0.002**	**-0.004**	**0.000**	0,000	**0.000**	**0.001**
	(0.000)		**(0.029)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.006)**	(0.612)	**(0.078)**	**(0.000)**
c_{11}	**0.000**		**0.000**	**0.000**	**0.000**		**0.000**	**0.000**	**0.000**	**0.005**	**0.000**	**0.000**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.001)**	**(0.000)**
c_{22}	**0.003**		**0.004**	**0.004**	**0.000**		**0.001**	**0.001**	**0.001**	**0.002**	**0.001**	**0.003**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
c_{12}	**0.005**		**0.001**	**0,000**	**0.000**		0.000	**0.002**	**0.000**	**0.004**	**0.000**	**0.000**
	(0.000)		**(0.039)**	**(0.066)**	**(0.002)**		(0.117)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.002)**
b_{11}	**0.905**		**0.697**	**0.916**	**0.895**		**0.634**	**0.942**	**0.879**	**-0.927**	**0.833**	**0.840**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
b_{22}	**0.457**		**0.398**	**0.195**	**0.692**		**0.532**	**0.220**	**0.478**	**0.271**	**0.626**	**0.236**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.004)**	**(0.000)**	**(0.001)**	**(0.000)**	**(0.000)**
b_{12}	**-0.992**		**0.557**	**0.895**	**0.935**		0.084	**-0.977**	**0.783**	**-0.938**	**0.771**	**0.870**
	(0.000)		**(0.005)**	**(0.000)**	**(0.000)**		(0.867)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
a_{11}	**0.072**		**0.333**	**0.060**	**0.094**		**0.380**	**0.041**	**0.077**	0.022	**0.165**	**0.077**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.121)	**(0.000)**	**(0.000)**
a_{22}	**0.568**		**0.855**	**0.678**	**0.202**		**0.238**	**0.347**	**0.379**	**0.446**	**0.400**	**0.366**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
a_{12}	0.002		**0.147**	**0.027**	**0.029**		**0.110**	-0.005	**0.080**	**0.019**	**0.188**	**0.024**
	(0.127)		**(0.031)**	**(0.056)**	**(0.002)**		**(0.082)**	(0.473)	**(0.000)**	**(0.028)**	**(0.000)**	**(0.038)**

Table 10: Parameter estimates of the GARCH models

Mean equation: $\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$

	Germany-Spain				Germany-Ireland				Germany-Greece			
Coefficient	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT
β_{01}	**-0.004**		0.002	**-0.005**	**-0.003**		**0.004**	**-0.006**	**-0.002**	-0.003	**0.005**	
	(0.000)		(0.285)	**(0.001)**	**(0.012)**		**(0.061)**	**(0.001)**	**(0.044)**	(0.358)	**(0.032)**	
β_{02}	**-0.011**		-0.003	**-0.010**	0.004		**0.016**	-0.006	**-0.005**	-0.005	-0.003	
	(0.000)		(0.550)	**(0.000)**	(0.300)		**(0.010)**	(0.442)	**(0.000)**	(0.286)	(0.219)	
β_{11}	0.067		**-2.073**	**0.640**	-0.028		**-1.923**	0.353	-0.006	-1.476	**-1.918**	
	(0.704)		**(0.007)**	**(0.014)**	(0.890)		**(0.009)**	(0.321)	(0.974)	(0.218)	**(0.034)**	
β_{12}	**-0.775**		**-1.170**	0.000	0.080		0.079	**3.531**	-0.001	**1.410**	0.000	
	(0.000)		**(0.000)**	(1.00)	(0.344)		(0.435)	**(0.027)**	(0.195)	**(0.066)**	(0.496)	
β_{21}	0.080		**-1.250**	**2.190**	**2.241**		**1.126**	**4.311**	-0.010	-0.635	0.010	
	(0.683)		**(0.001)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	(0.797)	(0.325)	(0.911)	
β_{22}	**2.207**		**2.335**	**1.847**	-0.359		-0.759	-3.634	0.032	**-1.251**	0.093	
	(0.000)		**(0.009)**	**(0.000)**	(0.658)		(0.485)	(0.317)	(0.519)	**(0.073)**	(0.233)	
β_{31}	**0.005**		**0.011**	**0.011**	**0.006**		**0.011**	**0.016**	**0.009**	**-0.004**	**0.014**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.014)**	**(0.000)**	
β_{32}	-0.001		0.004	-0.001	**0.016**		**0.010**	**0.108**	**-0.005**	**0.580**	-0.006	
	(0.196)		(0.171)	(0.246)	**(0.000)**		**(0.008)**	**(0.000)**	**(0.036)**	**(0.002)**	(0.134)	
β_{41}	0.070		**-0.177**	0.020	**0.079**		**-0.213**	-0.004	0.048	**0.117**	**-0.199**	
	(0.135)		**(0.002)**	(0.857)	**(0.095)**		**(0.000)**	(0.970)	(0.260)	**(0.064)**	**(0.000)**	
β_{42}	0.094		**-0.491**	-0.048	0.161		-0.262	0.326	**0.203**	**0.216**	**0.210**	
	(0.146)		**(0.022)**	(0.616)	(0.320)		(0.359)	(0.595)	**(0.000)**	**(0.043)**	**(0.004)**	
β_{51}	**0.003**		**0.004**	**0.004**	**0.004**		**0.005**	**0.007**	**0.006**	0.001	**0.007**	
	(0.000)		**(0.000)**	**(0.076)**	**(0.000)**		**(0.000)**	**(0.001)**	**(0.000)**	(0.704)	**(0.000)**	
β_{52}	**0.001**		**0.002**	0.000	**0.002**		**0.002**	**0.014**	0.000	**-0.002**	0.000	
	(0.000)		**(0.000)**	(0.389)	**(0.000)**		**(0.000)**	**(0.000)**	(0.924)	**(0.002)**	(0.859)	
c_{11}	**0.000**		**0.000**	**0.000**	**0.000**		**0.000**	**0.000**	**0.000**	0.000	**0.000**	
	(0.000)		**(0.018)**	**(0.000)**	**(0.000)**		**(0.039)**	**(0.000)**	**(0.000)**	(0.711)	**(0.054)**	
c_{22}	**0.001**		**0.003**	**0.001**	**0.003**		**0.009**	**0.004**	**0.001**	**0.003**	**0.000**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.001)**	**(0.005)**	
c_{12}	**0.000**		**0.000**	**0.000**	**0.000**		**0.001**	0.003	**0.000**	**0.002**	0.000	
	(0.000)		**(0.011)**	**(0.027)**	**(0.000)**		**(0.000)**	(0.111)	**(0.001)**	**(0.035)**	(0.173)	
b_{11}	**0.899**		**0.792**	**0.918**	**0.908**		**0.779**	**0.899**	**0.889**	**0.982**	**0.779**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
b_{22}	**0.653**		**0.560**	**0.240**	**0.547**		**0.294**	**0.713**	**0.620**	0.147	**0.869**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.429)	**(0.000)**	
b_{12}	**0.876**		**0.815**	**0.943**	**0.787**		**0.545**	-0.346	**0.930**	-0.022	**0.929**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	(0.656)	**(0.000)**	(0.965)	**(0.000)**	
a_{11}	**0.090**		**0.238**	**0.057**	**0.084**		**0.265**	**0.074**	**0.102**	0.013	**0.266**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.125)	**(0.000)**	
a_{22}	**0.358**		**0.438**	**0.564**	**0.672**		**1.345**	**0.308**	**0.221**	**0.188**	**0.102**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.017)**	**(0.000)**	
a_{12}	**0.066**		**0.100**	**0.024**	**0.072**		**0.181**	**-0.043**	**0.030**	**-0.083**	**0.047**	
	(0.000)		**(0.009)**	**(0.006)**	**(0.000)**		**(0.020)**	**(0.095)**	**(0.000)**	**(0.048)**	**(0.021)**	

Table 11: Parameter estimates of the GARCH models

Mean equation: $\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$

	France-Italy				France-Portugal				France-Spain			
Coefficient	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT
β_{01}	-0.002		**0.014**	**-0.007**	-0.002		**0.014**	**-0.008**	**-0.004**		**0.013**	**-0.007**
	(0.156)		**(0.000)**	**(0.005)**	(0.120)		**(0.000)**	**(0.001)**	**(0.010)**		**(0.000)**	**(0.004)**
β_{02}	**-0.007**		**-0.006**	**-0.009**	**-0.008**		0,000	**-0.011**	**-0.011**		0.008	**-0.011**
	(0.000)		**(0.003)**	**(0.000)**	**(0.000)**		(0.911)	**(0.000)**	**(0.000)**		(0.137)	**(0.000)**
β_{11}	0.495		**-1.976**	**1.828**	**0.905**		**-2.967**	0.212	**-1.378**		**-3.983**	-0.380
	(0.308)		**(0.028)**	**(0.005)**	**(0.023)**		**(0.000)**	(0.745)	**(0.015)**		**(0.000)**	(0.626)
β_{12}	**0.063**		0.049	**0.148**	-0.001		-0.020	0.005	-0.235		**-0.565**	0.062
	(0.013)		(0.211)	**(0.051)**	(0.879)		(0.112)	(0.483)	(0.103)		**(0.057)**	(0.619)
β_{21}	0.375		-0.798	-0.204	0.003		**-1.209**	**2.379**	**3.468**		0.260	**5.231**
	(0.208)		(0.205)	(0.567)	(0.982)		**(0.000)**	**(0.000)**	**(0.000)**		(0.767)	**(0.000)**
β_{22}	**0.747**		0.023	**1.562**	**0.987**		0.386	**2.192**	**2.747**		0.764	**1.444**
	(0.000)		(0.937)	**(0.000)**	**(0.000)**		(0.472)	**(0.000)**	**(0.000)**		(0.486)	**(0.000)**
β_{31}	**0.009**		**0.004**	**0.024**	**0.007**		0.003	**0.017**	**0.005**		0.002	**0.021**
	(0.000)		**(0.025)**	**(0.000)**	**(0.000)**		(0.174)	**(0.000)**	**(0.000)**		(0.369)	**(0.000)**
β_{32}	**-0.010**		**-0.011**	**-0.011**	**0.003**		0.001	**0.009**	**-0.002**		-0.001	-0.001
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		(0.351)	**(0.000)**	**(0.008)**		(0.534)	(0.167)
β_{41}	**0.160**		-0.040	-0.099	**0.155**		-0.010	-0.192	0.095		-0.056	-0.236
	(0.066)		(0.743)	(0.497)	**(0.035)**		(0.942)	(0.175)	(0.254)		(0.716)	(0.105)
β_{42}	**0.161**		**0.170**	-0.018	**0.142**		0.128	0.032	**0.138**		-0.190	0.021
	(0.000)		**(0.028)**	(0.808)	**(0.005)**		(0.179)	(0.806)	**(0.034)**		(0.347)	(0.803)
β_{51}	**0.006**		**0.006**	**0.008**	**0.003**		**0.005**	0.002	**0.003**		**0.003**	**0.006**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	(0.202)	**(0.000)**		**(0.000)**	**(0.000)**
β_{52}	**-0.003**		**-0.002**	**-0.004**	**0.001**		**0.001**	**0.001**	**0.001**		**0.001**	0.000
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**		**(0.014)**	(0.323)
c_{11}	**0.000**		0.000	**0.000**	**0,000**		**0.000**	**0.000**	**0.000**		**0.001**	**0.000**
	(0.000)		(0.597)	**(0.000)**	**(0.000)**		**(0.035)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**
c_{22}	**0.001**		**0.001**	**0.001**	**0.001**		**0.000**	**0.002**	**0.000**		**0.010**	**0.001**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.001)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**
c_{12}	**0.001**		0.001	**0.001**	**0,000**		**0.001**	**0.001**	**0.000**		**0.003**	**0.001**
	(0.000)		(0.103)	**(0.032)**	**(0.000)**		**(0.014)**	**(0.031)**	**(0.000)**		**(0.000)**	**(0.001)**
b_{11}	**0.856**		**0.696**	**0.824**	**0.847**		**0.681**	**0.856**	**0.859**		**0.674**	**0.821**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**
b_{22}	**0.564**		**0.557**	**0.280**	**0.670**		**0.625**	**0.363**	**0.702**		**0.113**	**0.232**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**		**(0.009)**	**(0.000)**
b_{12}	**-0.746**		**-0.890**	-0.391	**0.830**		-0.197	**0.714**	**0.847**		**0.496**	0.156
	(0.000)		**(0.000)**	(0.539)	**(0.000)**		(0.660)	**(0.000)**	**(0.000)**		**(0.000)**	(0.486)
a_{11}	**0.167**		**0.565**	**0.132**	**0.171**		**0.574**	**0.095**	**0.162**		**0.522**	**0.125**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**
a_{22}	**0.259**		**0.240**	**0.350**	**0.308**		**0.464**	**0.359**	**0.301**		**0.768**	**0.565**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**
a_{12}	**0.060**		0.048	0.048	**0.102**		**0.206**	**0.049**	**0.090**		**0.297**	**0.144**
	(0.004)		(0.176)	(0.165)	**(0.000)**		**(0.020)**	**(0.017)**	**(0.000)**		**(0.000)**	**(0.000)**

Table 12: Parameter estimates of the GARCH models

Mean equation: $\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$

	France-Ireland				France-Greece				Italy-Portugal			
Coefficient	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT
β_{01}	-0.003		**0.015**	**-0.007**	0.000		**0.011**		**-0.003**		**-0.003**	**-0.003**
	(0.109)		**(0.000)**	**(0.004)**	(0.200)		**(0.000)**		**(0.000)**		**(0.042)**	**(0.008)**
β_{02}	0.002		**0.018**	-0.011	**-0.010**		0.000		**-0.008**		**-0.001**	**-0.010**
	(0.668)		**(0.009)**	(0.188)	**(0.000)**		(0.111)		**(0.000)**		**(0.042)**	**(0.000)**
β_{11}	-0.484		**-2.066**	-0.481	0.380		-1.130		-0.007		-0.023	**0.213**
	(0.243)		**(0.017)**	(0.545)	(0.390)		(0.322)		(0.776)		(0.354)	**(0.000)**
β_{12}	0.048		0.070	0.956	0.000		0.000		**-0.020**		**-0.033**	-0.011
	(0.621)		(0.539)	(0.608)	(0.130)		(0.717)		**(0.001)**		**(0.075)**	(0.116)
β_{21}	**1.738**		**0.906**	**4.848**	**0.330**		**0.341**		**0.117**		0.028	0.104
	(0.000)		**(0.006)**	**(0.000)**	**(0.000)**		**(0.000)**		**(0.002)**		(0.699)	(0.142)
β_{22}	-0.590		-1.008	2.715	0.050		0.021		**0.957**		**1.263**	**0.760**
	(0.346)		(0.283)	(0.458)	(0.150)		(0.734)		**(0.000)**		**(0.000)**	**(0.000)**
β_{31}	**0.005**		0.002	**0.021**	**0.010**		**0.000**		**-0.010**		**-0.011**	**-0.010**
	(0.000)		(0.322)	**(0.000)**	**(0.000)**		**(0.015)**		**(0.000)**		**(0.000)**	**(0.000)**
β_{32}	**0.014**		**0.010**	**0.076**	**-0.010**		**-0.012**		**0.005**		0.002	**0.011**
	(0.000)		**(0.021)**	**(0.000)**	**(0.040)**		**(0.072)**		**(0.000)**		(0.111)	**(0.000)**
β_{41}	0.124		-0.069	-0.158	**0.140**		-0.101		**0.137**		**0.102**	0.037
	(0.108)		(0.638)	(0.302)	**(0.080)**		(0.423)		**(0.000)**		**(0.011)**	(0.483)
β_{42}	0.092		-0.138	0.104	**0.200**		**0.247**		**0.135**		**0.234**	0.050
	(0.603)		(0.684)	(0.858)	**(0.000)**		**(0.000)**		**(0.015)**		**(0.008)**	(0.687)
β_{51}	**0.003**		**0.004**	**0.006**	**0.010**		**0.018**		**-0.002**		**-0.002**	**-0.003**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**		**(0.000)**		**(0.000)**	**(0.000)**
β_{52}	**0.002**		**0.002**	**0.009**	0.000		0.000		**0.001**		**0.001**	**0.003**
	(0.000)		**(0.000)**	**(0.002)**	(0.940)		(0.971)		**(0.000)**		**(0.000)**	**(0.000)**
c_{11}	**0.000**		**0.000**	**0.000**	**0.000**		0.000		**0.000**		**0.000**	**0.000**
	(0.000)		**(0.021)**	**(0.000)**	**(0.000)**		(0.493)		**(0.000)**		**(0.049)**	**(0.001)**
c_{22}	**0.003**		**0.011**	**0.005**	**0.000**		**0.000**		**0.000**		**0.000**	**0.001**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.012)**		**(0.000)**		**(0.000)**	**(0.000)**
c_{12}	**0.001**		**0.006**	**0.001**	**0.000**		**0.000**		**0.000**		**0.000**	**0.000**
	(0.000)		**(0.000)**	**(0.049)**	**(0.000)**		**(0.053)**		**(0.000)**		**(0.046)**	**(0.003)**
b_{11}	**0.842**		**0.674**	**0.815**	**0.840**		**0.711**		**0.943**		**0.907**	**0.692**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**		**(0.000)**		**(0.000)**	**(0.000)**
b_{22}	**0.565**		**0.294**	**0.714**	**0.500**		**0.863**		**0.692**		**0.563**	**0.497**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**		**(0.000)**		**(0.000)**	**(0.000)**
b_{12}	**0.724**		-0.427	**0.813**	**0.750**		**-0.636**		**0.892**		**0.462**	**0.715**
	(0.000)		(0.111)	**(0.000)**	**(0.000)**		**(0.023)**		**(0.000)**		**(0.040)**	**(0.000)**
a_{11}	**0.176**		**0.569**	**0.130**	**0.200**		**0.560**		**0.037**		**0.052**	**0.107**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**		**(0.000)**		**(0.002)**	**(0.000)**
a_{22}	**0.618**		**1.266**	**0.293**	**0.300**		**0.126**		**0.296**		**0.530**	**0.325**
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**		**(0.000)**		**(0.000)**	**(0.000)**
a_{12}	**0.146**		**0.265**	**0.053**	**0.090**		**0.144**		**0.049**		**0.118**	**0.067**
	(0.000)		**(0.012)**	**(0.029)**	**(0.000)**		**(0.057)**		**(0.000)**		**(0.002)**	**(0.008)**

Table 13: Parameter estimates of the GARCH models

Mean equation: $\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$

	Italy-Spain				Italy-Ireland				Italy-Greece			
Coefficient	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT
β_{01}	**-0.003**		**-0.003**	**-0.003**	**-0.002**		**-0.002**	**-0.003**	**-0.002**	-0.002	-0.002	
	(0.001)		**(0.050)**	**(0.003)**	**(0.003)**		**(0.073)**	**(0.003)**	**(0.034)**	(0.581)	(0.201)	
β_{02}	**-0.010**		-0.003	**-0.012**	0.003		**0.017**	-0.007	**-0.004**	-0.004	-0.003	
	(0.000)		(0.609)	**(0.000)**	(0.456)		**(0.015)**	(0.408)	**(0.000)**	(0.380)	(0.243)	
β_{11}	**-0.088**		**-0.082**	-0.033	-0.049		**-0.056**	**-0.253**	-0.024	-1.035	-0.041	
	(0.011)		**(0.041)**	(0.686)	(0.456)		**(0.002)**	**(0.001)**	(0.204)	(0.455)	(0.108)	
β_{12}	-0.169		0.071	-0.210	0.131		**0.232**	3.531	0.000	0.694	0.000	
	(0.259)		(0.876)	(0.447)	(0.228)		**(0.068)**	(0.154)	(0.472)	(0.319)	(0.798)	
β_{21}	**0.401**		0.177	**0.691**	**0.710**		**0.324**	**2.806**	-0.018	**1.337**	-0.014	
	(0.000)		(0.120)	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	(0.160)	**(0.096)**	(0.466)	
β_{22}	**0.506**		-0.719	**0.613**	0.281		**-1.638**	0.157	-0.024	0.236	-0.018	
	(0.000)		(0.117)	**(0.012)**	(0.407)		**(0.015)**	(0.946)	(0.349)	(0.819)	(0.703)	
β_{31}	**-0.010**		**-0.011**	**-0.010**	**-0.010**		**-0.011**	**-0.009**	**-0.009**	**-0.008**	**-0.011**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
β_{32}	**-0.001**		0.000	**-0.002**	**0.018**		**0.012**	**0.146**	**-0.005**	0.179	**-0.009**	
	(0.025)		(0.931)	**(0.004)**	**(0.000)**		**(0.005)**	**(0.000)**	**(0.000)**	(0.345)	**(0.013)**	
β_{41}	**0.135**		**0.108**	0.057	**0.165**		**0.140**	**0.075**	**0.147**	**0.180**	**0.099**	
	(0.000)		**(0.005)**	(0.267)	**(0.000)**		**(0.000)**	**(0.097)**	**(0.000)**	**(0.016)**	**(0.011)**	
β_{42}	**0.184**		**-0.355**	0.070	0.128		-0.264	0.328	**0.218**	0.232	**0.222**	
	(0.004)		**(0.096)**	(0.417)	(0.436)		(0.467)	(0.569)	**(0.000)**	(0.025)	**(0.003)**	
β_{51}	**-0.002**		**-0.002**	**-0.002**	**-0.002**		**-0.001**	**-0.002**	**-0.001**	**-0.001**	**-0.001**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.021)**	**(0.000)**	
β_{52}	**0.003**		**0.003**	**0.001**	**0.003**		**0.002**	**0.020**	0.000	-0.001	0.000	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	(0.327)	(0.334)	(0.688)	
c_{11}	**0.000**		**0.000**	**0.000**	**0.000**		**0.000**	**0.000**	**0.000**	0.000	**0.000**	
	(0.000)		**(0.053)**	**(0.000)**	**(0.000)**		**(0.056)**	**(0.000)**	**(0.000)**	(0.207)	**(0.034)**	
c_{22}	**0.000**		**0.002**	**0.001**	**0.002**		**0.009**	**0.003**	**0.001**	**0.003**	**0.000**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.002)**	
c_{12}	**0.000**		0.001	**0.000**	**0.000**		0.000	0.000	**0.002**	**0.003**	**0.000**	
	(0.000)		(0.213)	**(0.000)**	**(0.043)**		(0.241)	(0.527)	**(0.000)**	**(0.052)**	**(0.044)**	
b_{11}	**0.946**		**0.890**	**0.637**	**0.948**		**0.879**	**0.723**	**0.839**	**0.891**	**0.902**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
b_{22}	**0.718**		**0.616**	**0.318**	**0.556**		**0.291**	**0.735**	**0.339**	0.146	**0.876**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.403)	**(0.000)**	
b_{12}	**0.905**		0.249	**0.770**	**0.777**		0.403	**-0.973**	-0.379	-0.116	**0.926**	
	(0.000)		(0.659)	**(0.000)**	**(0.000)**		(0.131)	**(0.000)**	(0.237)	(0.843)	**(0.000)**	
a_{11}	**0.036**		**0.054**	**0.124**	**0.036**		**0.063**	**0.124**	**0.048**	0.031	**0.049**	
	(0.000)		**(0.008)**	**(0.000)**	**(0.000)**		**(0.005)**	**(0.000)**	**(0.000)**	(0.232)	**(0.002)**	
a_{22}	**0.316**		**0.388**	**0.568**	**0.682**		**1.353**	**0.284**	**0.294**	**0.201**	**0.102**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.005)**	**(0.000)**	
a_{12}	**0.047**		**0.106**	**0.060**	**0.054**		**0.174**	**0.014**	**-0.033**	**-0.057**	**0.034**	
	(0.000)		**(0.019)**	**(0.010)**	**(0.006)**		**(0.018)**	**(0.023)**	**(0.007)**	**(0.074)**	**(0.000)**	

Table 14: Parameter estimates of the GARCH models

Mean equation: $\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$

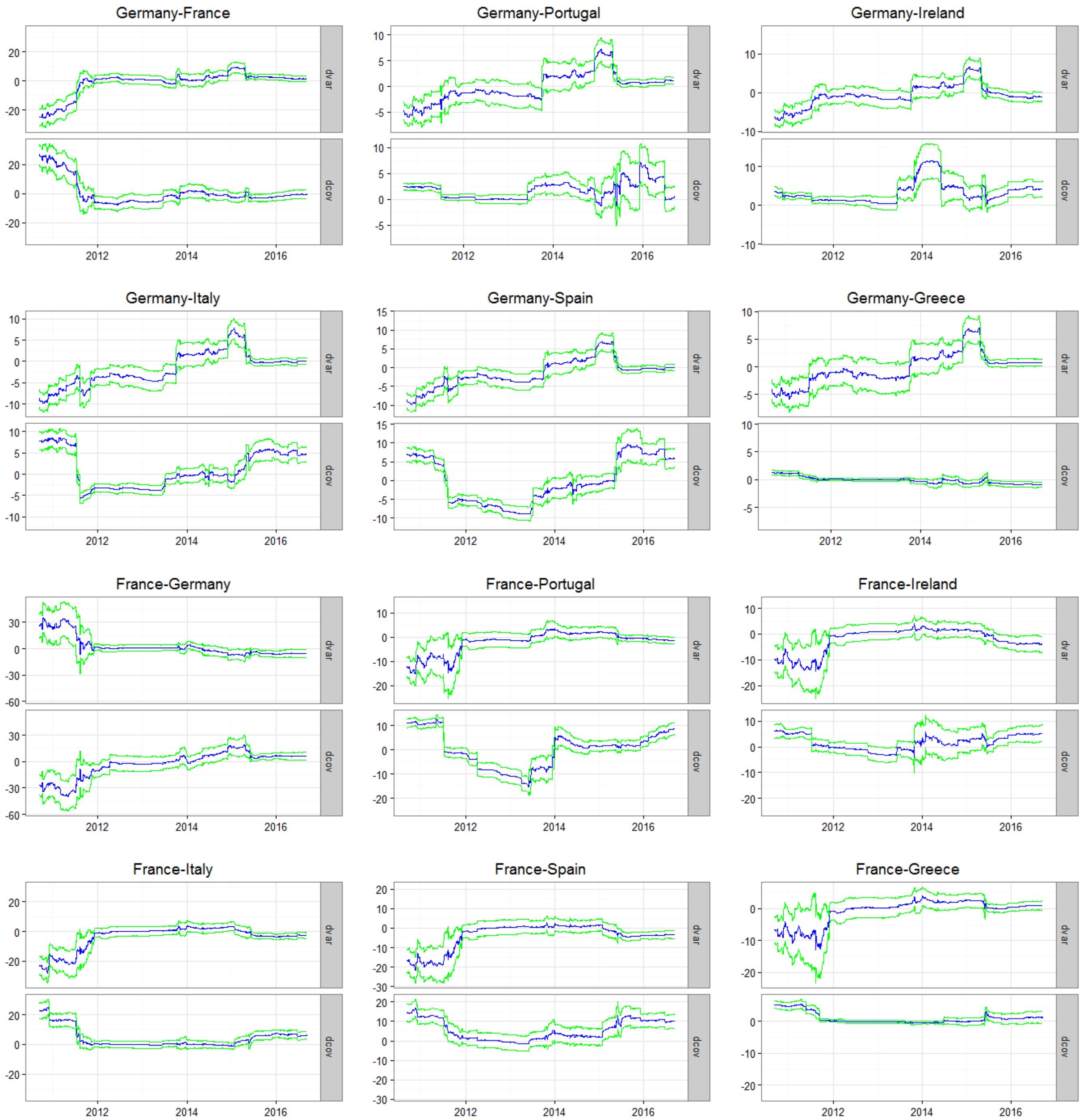
	Portugal-Spain				Portugal-Ireland				Portugal-Greece			
Coefficient	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT
β_{01}	**-0.004**		0.000	**-0.005**	**-0.003**		0.001	**-0.005**	**-0.003**	-0.004	0.000	
	(0.000)		(0.794)	**(0.001)**	**(0.002)**		(0.420)	**(0.003)**	**(0.002)**	(0.154)	(0.807)	
β_{02}	**-0.010**		-0.003	**-0.009**	0.002		**0.017**	-0.006	**-0.005**	-0.004	-0.003	
	(0.000)		(0.635)	**(0.000)**	(0.540)		**(0.011)**	(0.439)	**(0.000)**	(0.410)	(0.162)	
β_{11}	**-0.055**		**-0.029**	**-0.053**	-0.007		0.005	**-0.037**	-0.002	-1.992	**0.017**	
	(0.000)		**(0.006)**	**(0.000)**	(0.250)		(0.639)	**(0.000)**	(0.407)	(0.128)	**(0.000)**	
β_{12}	**0.351**		**-1.159**	0.188	0.143		0.078	1.850	-0.001	0.451	0.000	
	(0.000)		**(0.000)**	(0.236)	(0.391)		(0.589)	(0.256)	(0.253)	(0.569)	(0.670)	
β_{21}	**1.671**		**1.138**	**1.732**	**0.087**		**0.058**	**2.166**	**0.107**	**2.814**	**0.097**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.035)**	**(0.000)**	**(0.000)**	**(0.004)**	**(0.000)**	
β_{22}	**0.163**		**0.525**	**0.312**	-0.047		0.021	1.366	0.021	0.853	0.000	
	(0.091)		**(0.000)**	**(0.021)**	(0.853)		(0.941)	(0.234)	(0.301)	(0.388)	(0.994)	
β_{31}	**0.005**		**0.005**	**0.009**	**0.005**		**0.005**	**0.011**	**0.006**	0.000	**0.005**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.951)	**(0.000)**	
β_{32}	**-0.001**		0.000	**-0.001**	**0.018**		**0.012**	**0.128**	**-0.004**	**0.799**	**-0.008**	
	(0.032)		(0.986)	**(0.047)**	**(0.000)**		**(0.004)**	**(0.000)**	**(0.063)**	**(0.000)**	**(0.053)**	
β_{41}	**0.132**		0.031	**0.139**	**0.111**		-0.022	**0.177**	**0.106**	0.074	-0.015	
	(0.001)		(0.496)	**(0.083)**	**(0.002)**		(0.656)	**(0.032)**	**(0.003)**	(0.311)	(0.746)	
β_{42}	**0.135**		-0.333	0.082	0.116		-0.203	0.318	**0.203**	**0.261**	**0.221**	
	(0.029)		(0.129)	(0.303)	(0.466)		(0.531)	(0.591)	**(0.000)**	**(0.016)**	**(0.002)**	
β_{51}	**0.001**		**0.001**	**0.001**	**0.001**		**0.001**	**0.002**	**0.001**	0.001	**0.001**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.165)	**(0.000)**	
β_{52}	**0.001**		**0.003**	0.000	**0.002**		**0.002**	**0.017**	0.000	**-0.002**	0.000	
	(0.000)		**(0.000)**	(0.638)	**(0.000)**		**(0.000)**	**(0.000)**	(0.743)	**(0.000)**	(0.965)	
c_{11}	**0.000**		**0.000**	**0.000**	**0.000**		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.001)**	**(0.001)**	**(0.000)**	**(0.096)**	**(0.001)**	
c_{22}	**0.000**		**0.003**	**0.001**	**0.002**		**0.010**	**0.004**	**0.001**	**0.003**	**0.000**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.001)**	**(0.003)**	
c_{12}	0.002		0.001	**0.002**	**0.000**		**0.002**	0.001	**0.000**	**0.003**	0.000	
	(0.626)		(0.230)	**(0.000)**	**(0.029)**		**(0.036)**	(0.274)	**(0.000)**	**(0.000)**	(0.144)	
b_{11}	**0.885**		**0.630**	**0.890**	**0.898**		**0.589**	**0.907**	**0.901**	**0.967**	**0.658**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
b_{22}	**0.668**		**0.545**	**0.169**	**0.550**		**0.282**	**0.710**	**0.489**	0.136	**0.847**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	(0.496)	**(0.000)**	
b_{12}	-0.736		0.404	**-0.733**	**0.809**		-0.199	-0.287	**0.926**	-0.452	**0.940**	
	(0.836)		(0.397)	**(0.000)**	**(0.000)**		(0.653)	(0.781)	**(0.000)**	(0.234)	**(0.000)**	
a_{11}	**0.100**		**0.477**	**0.059**	**0.094**		**0.564**	**0.065**	**0.091**	**0.022**	**0.450**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.015)**	**(0.000)**	
a_{22}	**0.358**		**0.450**	**0.608**	**0.687**		**1.365**	**0.316**	**0.282**	**0.194**	**0.117**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.018)**	**(0.000)**	
a_{12}	-0.001		0.101	**-0.043**	**0.046**		0.138	-0.040	**0.028**	**-0.064**	**0.033**	
	(0.947)		(0.242)	**(0.068)**	**(0.018)**		(0.161)	(0.292)	**(0.000)**	**(0.012)**	**(0.051)**	

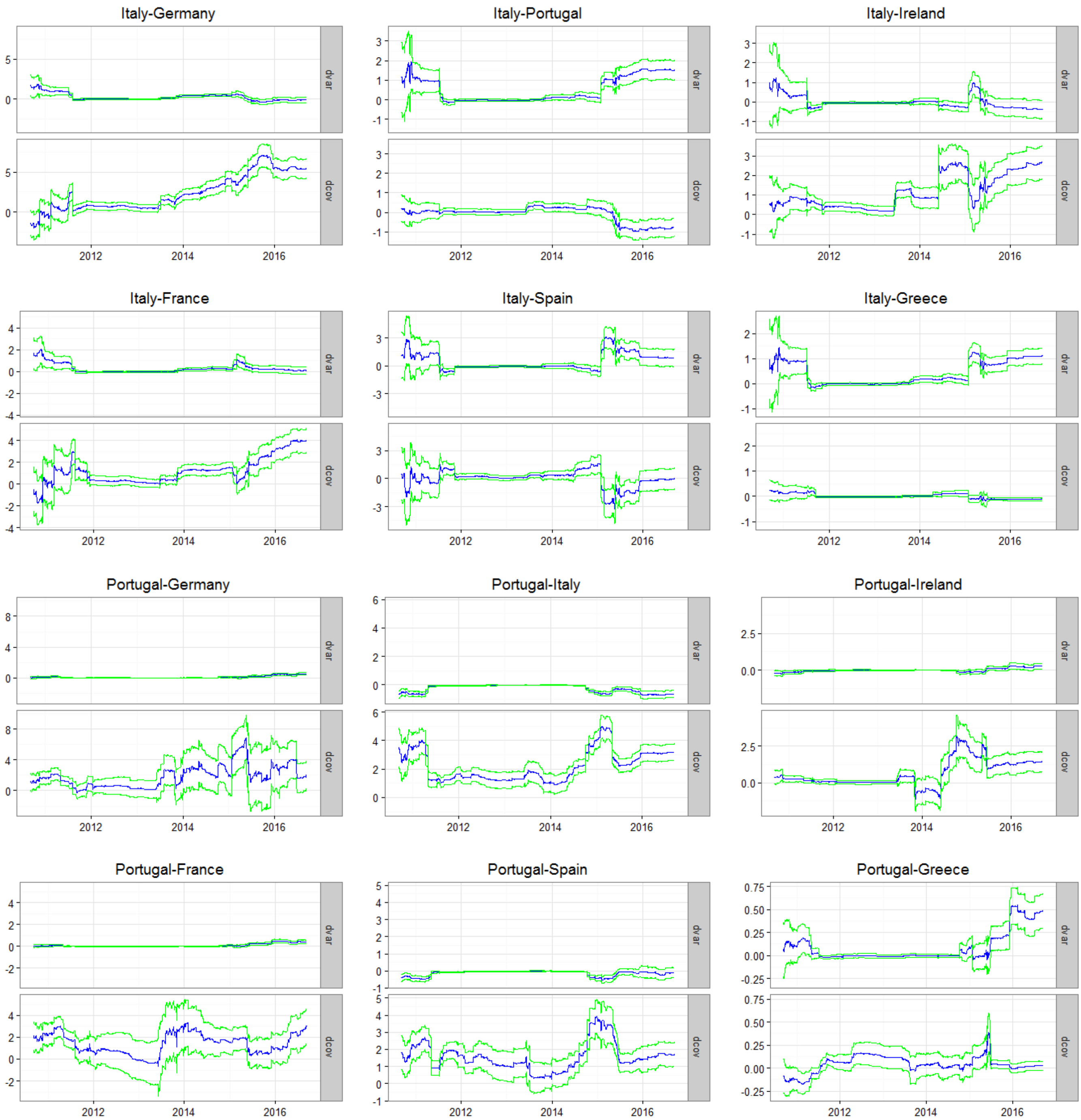
Table 15: Parameter estimates of the GARCH models

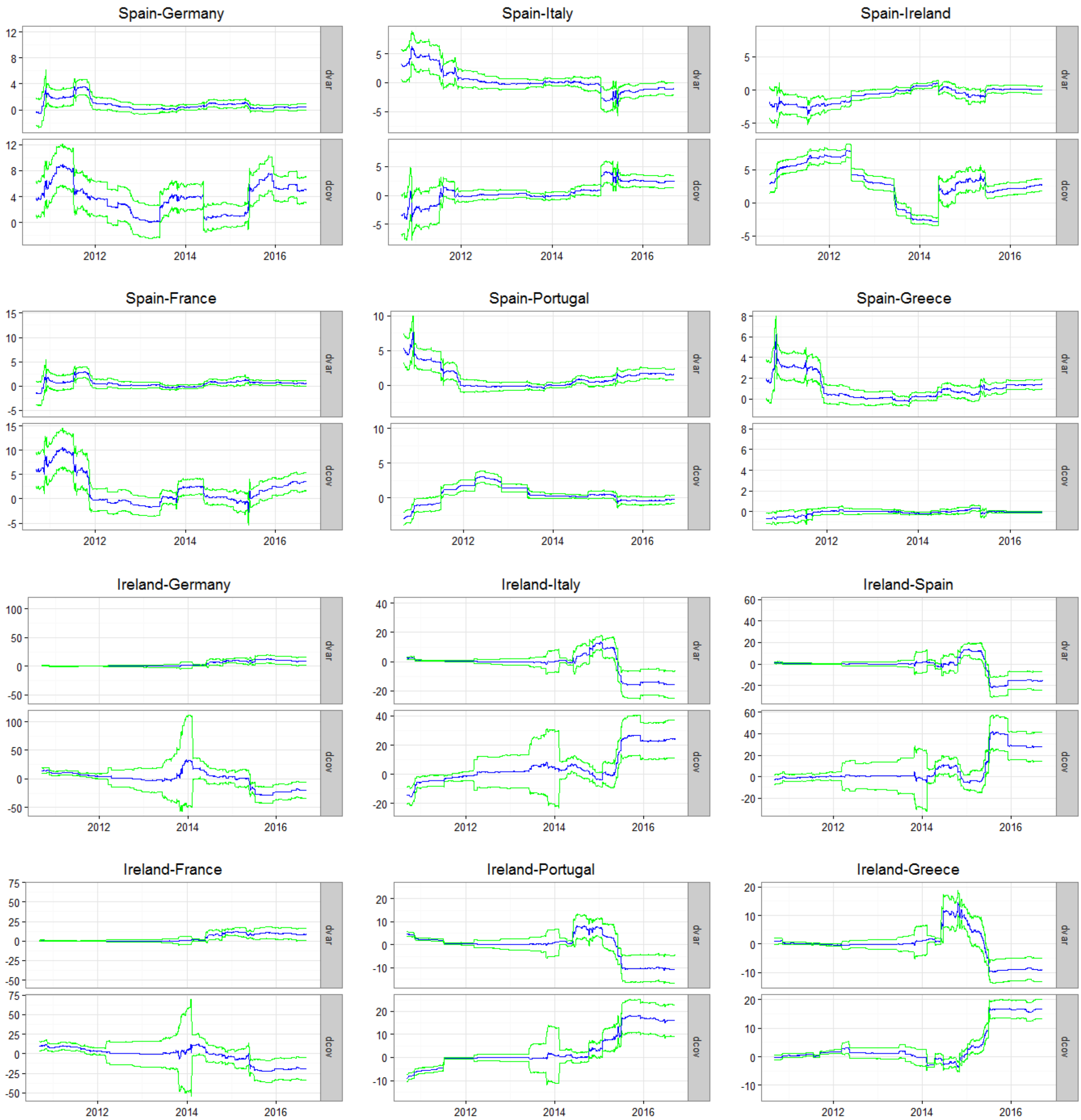
Mean equation: $\Delta R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta E_t(V_{i,t+1}) + \beta_{2,i}\Delta E_t(Cov_{ij,t+1}) + \beta_{3,i}\Delta Vstoxx_t + \beta_{4,i}\Delta r_t + \beta_{5,i}\Delta CDS_{i,t} + \varepsilon_{i,t}$

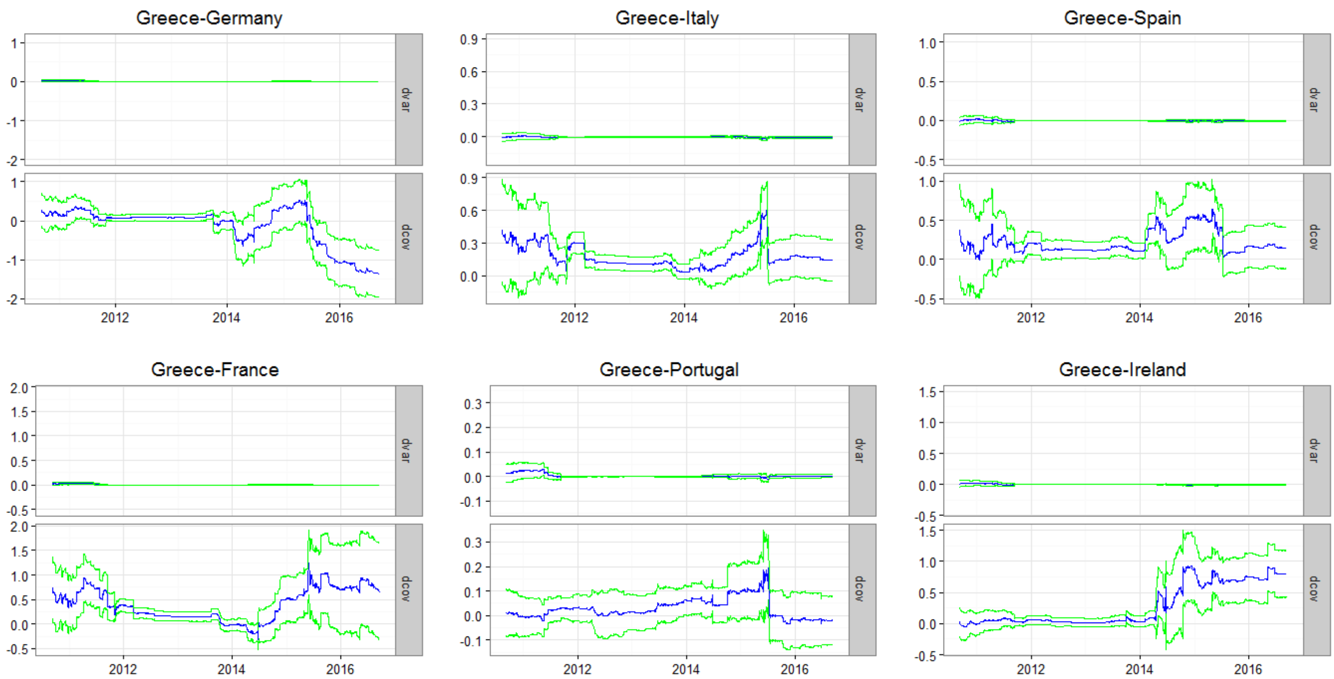
	Spain-Ireland				Spain-Greece				Ireland-Greece			
Coefficient	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT	Full sample	Pre-crisis	Crisis	Post-OMT
β_{01}	**-0.003**		-0.002	**-0.005**	**-0.003**	-0.004	0.000		0.001	-0.002	0.006	
	(0.013)		(0.566)	**(0.001)**	**(0.007)**	(0.183)	(0.908)		(0.787)	(0.631)	(0.187)	
β_{02}	0.004		**0.012**	-0.008	**-0.006**	-0.006	-0.004		**-0.005**	-0.003	**-0.004**	
	(0.248)		**(0.069)**	(0.367)	**(0.000)**	(0.188)	(0.118)		**(0.000)**	(0.475)	**(0.093)**	
β_{11}	**0.778**		**-0.547**	0.336	**0.735**	1.247	**-0.472**		0.013	-0.291	0.068	
	(0.000)		**(0.017)**	(0.111)	**(0.000)**	(0.382)	**(0.034)**		(0.878)	(0.678)	(0.545)	
β_{12}	**0.137**		0.037	1.742	-0.001	**1.683**	0.000		0.000	**-1.796**	0.000	
	(0.073)		(0.806)	(0.553)	(0.183)	**(0.023)**	(0.575)		(0.605)	**(0.071)**	(0.839)	
β_{21}	**0.855**		**0.376**	**2.435**	-0.018	**2.108**	**-0.117**		**0.975**	**3.961**	**0.966**	
	(0.000)		**(0.009)**	**(0.000)**	(0.683)	**(0.014)**	**(0.098)**		**(0.000)**	**(0.000)**	**(0.000)**	
β_{22}	**-0.558**		-0.486	2.465	0.046	0.356	0.030		**0.076**	**4.197**	0.045	
	(0.046)		(0.248)	(0.477)	(0.213)	(0.630)	(0.636)		**(0.010)**	**(0.000)**	(0.245)	
β_{31}	0.000		-0.002	**0.002**	0.000	-0.001	-0.001		**0.014**	**0.007**	**0.004**	
	(0.850)		(0.470)	**(0.006)**	(0.509)	(0.156)	(0.706)		**(0.000)**	**(0.006)**	**(0.059)**	
β_{32}	**0.014**		**0.008**	**0.122**	**-0.005**	**0.858**	**-0.008**		**-0.005**	**0.961**	**-0.007**	
	(0.000)		**(0.052)**	**(0.000)**	**(0.032)**	**(0.000)**	**(0.049)**		**(0.046)**	**(0.000)**	**(0.079)**	
β_{41}	0.064		-0.310	0.046	0.077	**0.118**	-0.304		0.175	0.016	**0.567**	
	(0.284)		(0.110)	(0.637)	(0.207)	**(0.098)**	(0.102)		(0.053)	(0.877)	**(0.000)**	
β_{42}	0.122		-0.412	0.419	**0.189**	**0.192**	**0.246**		**0.238**	**0.242**	**0.264**	
	(0.451)		(0.143)	(0.471)	**(0.000)**	**(0.068)**	**(0.000)**		**(0.000)**	**(0.032)**	**(0.000)**	
β_{51}	**0.003**		**0.003**	**0.002**	**0.003**	**0.002**	**0.004**		**0.002**	**0.002**	**0.002**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	
β_{52}	**0.002**		**0.002**	**0.016**	0.000	**-0.002**	0.000		0.000	**-0.003**	0.000	
	(0.000)		**(0.000)**	**(0.000)**	(0.917)	**(0.000)**	(0.921)		(0.864)	**(0.000)**	(0.925)	
c_{11}	**0.000**		**0.001**	**0.001**	**0.000**	**0.002**	**0.001**		**0.000**	**0.000**	**0.002**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.004)**		**(0.001)**	**(0.090)**	**(0.000)**	
c_{22}	**0.002**		**0.009**	**0.004**	**0.001**	**0.003**	**0.000**		**0.001**	**0.003**	**0.000**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	**(0.001)**	**(0.004)**		**(0.000)**	**(0.001)**	**(0.002)**	
c_{12}	**0.003**		**0.003**	0.000	**0.000**	**0.002**	0.000		**0.000**	0.001	0.001	
	(0.000)		**(0.005)**	(0.104)	**(0.000)**	**(0.005)**	(0.805)		**(0.001)**	(0.177)	(0.103)	
b_{11}	**0.876**		**0.718**	**0.472**	**0.892**	-0.046	**0.788**		**0.696**	**0.937**	**0.448**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	(0.535)	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	
b_{22}	**0.549**		**0.296**	**0.707**	**0.471**	0.224	**0.845**		**0.558**	0.182	**0.816**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	(0.160)	**(0.000)**		**(0.000)**	(0.296)	**(0.000)**	
b_{12}	**-0.658**		**0.524**	**0.680**	**0.899**	-0.187	-0.407		**0.489**	**0.555**	0.071	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	(0.552)	(0.279)		**(0.000)**	**(0.063)**	(0.848)	
a_{11}	**0.121**		**0.240**	**0.151**	**0.110**	**0.480**	**0.191**		**0.539**	**0.058**	**1.322**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.002)**	**(0.000)**	
a_{22}	**0.691**		**1.307**	**0.324**	**0.294**	**0.280**	**0.125**		**0.271**	**0.271**	**0.144**	
	(0.000)		**(0.000)**	**(0.000)**	**(0.000)**	**(0.003)**	**(0.000)**		**(0.000)**	**(0.001)**	**(0.000)**	
a_{12}	**0.139**		**0.263**	**0.095**	**0.053**	**0.135**	**0.116**		**0.171**	**0.083**	**0.200**	
	(0.000)		**(0.000)**	**(0.005)**	**(0.000)**	**(0.062)**	**(0.044)**		**(0.000)**	**(0.052)**	**(0.036)**	

Appendix E   Two-step Rolling Linear Regression Estimates

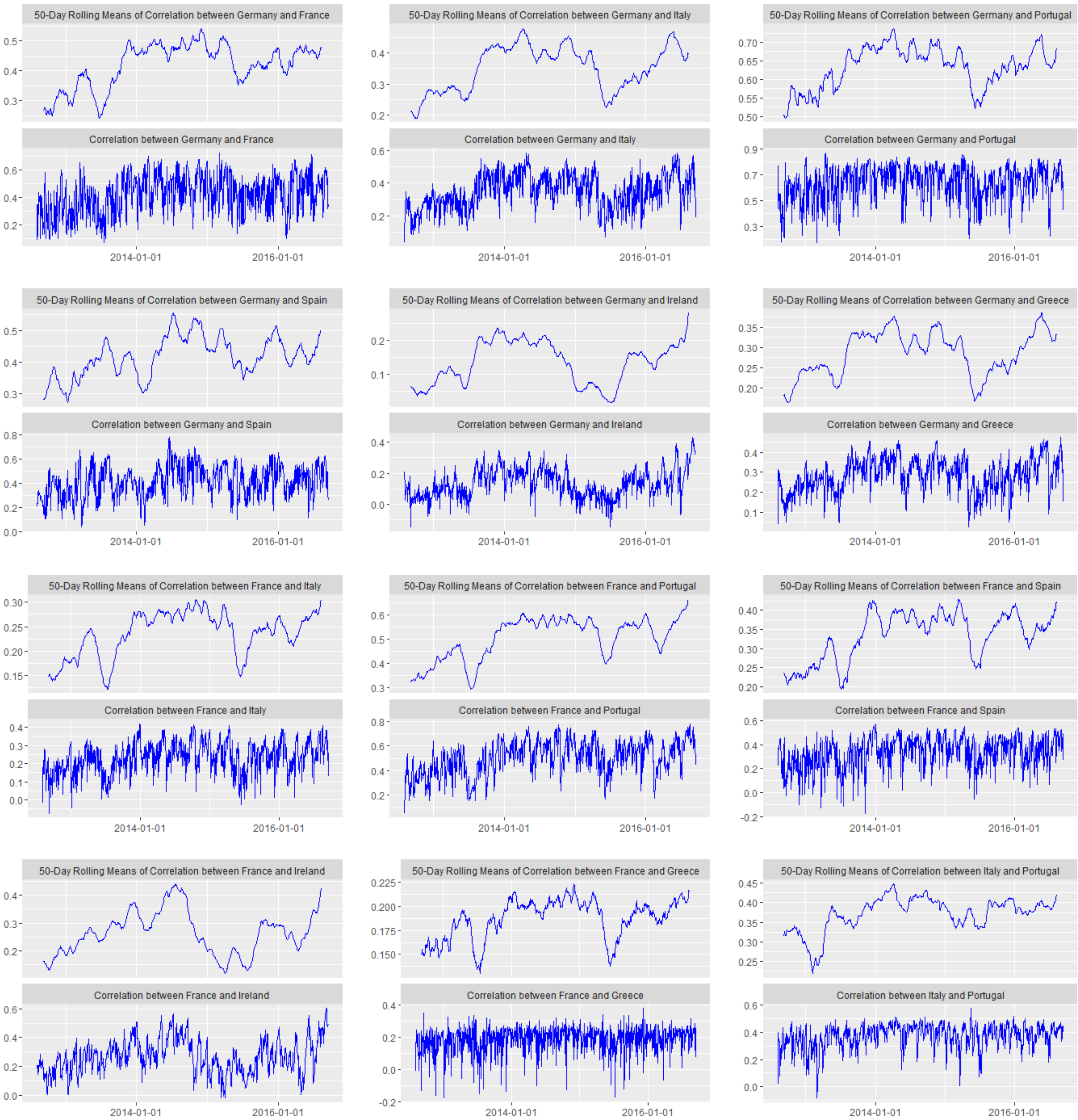


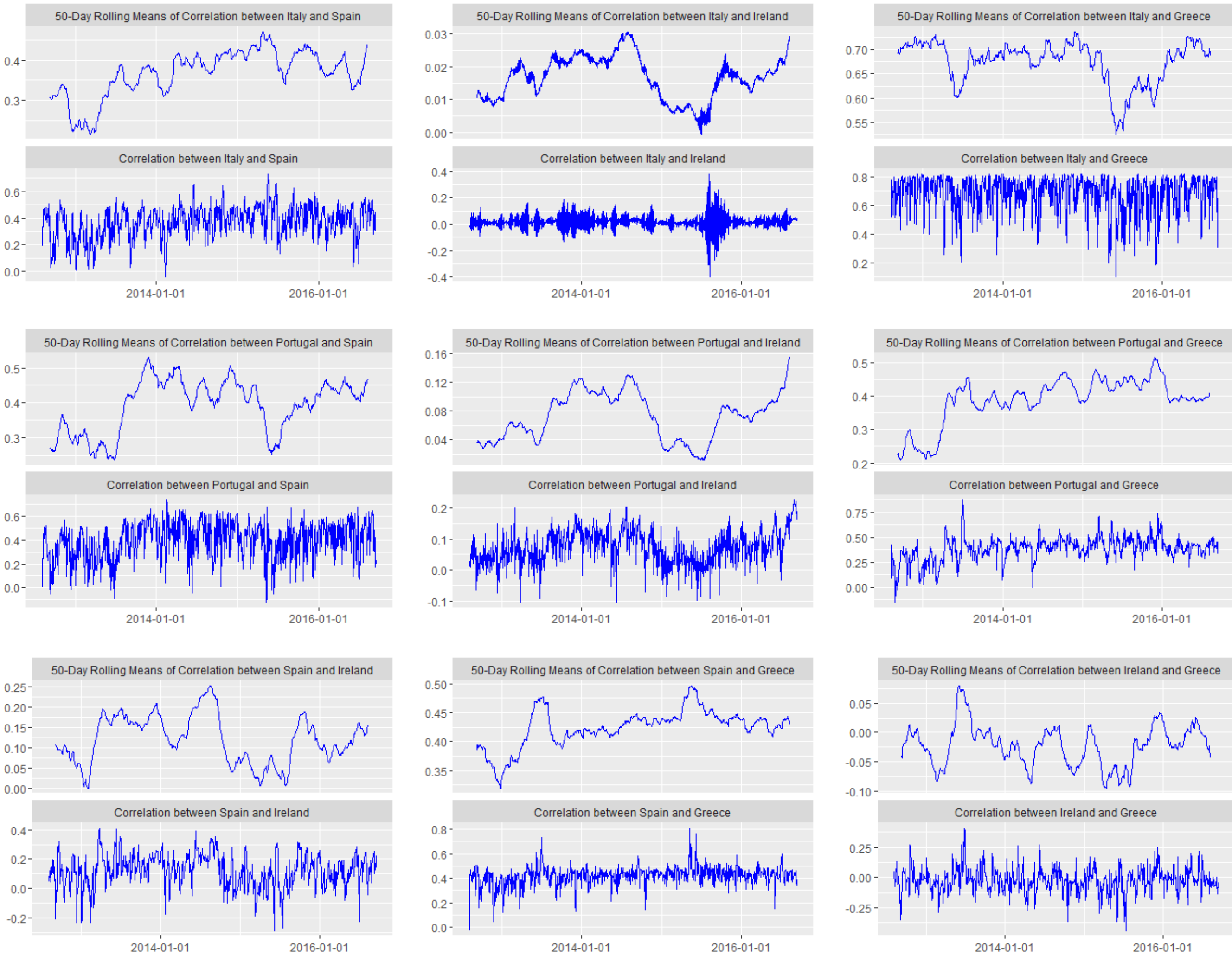

Italy-Germany
Italy-Portugal
Italy-Ireland
Italy-France
Italy-Spain
Italy-Greece
Portugal-Germany
Portugal-Italy
Portugal-Ireland
Portugal-France
Portugal-Spain
Portugal-Greece
dvar
dcov
2012
2014
2016


Spain-Germany
Spain-Italy
Spain-Ireland
Spain-France
Spain-Portugal
Spain-Greece
Ireland-Germany
Ireland-Italy
Ireland-Spain
Ireland-France
Ireland-Portugal
Ireland-Greece
dvar
dcov
2012
2014
2016


Greece-Germany
Greece-Italy
Greece-Spain
Greece-France
Greece-Portugal
Greece-Ireland
dvar
dcov
2012
2014
2016

Appendix F Conditional Correlation Dynamics




50-Day Rolling Means of Correlation between Italy and Spain
Correlation between Italy and Spain
50-Day Rolling Means of Correlation between Italy and Ireland
Correlation between Italy and Ireland
50-Day Rolling Means of Correlation between Italy and Greece
Correlation between Italy and Greece
50-Day Rolling Means of Correlation between Portugal and Spain
Correlation between Portugal and Spain
50-Day Rolling Means of Correlation between Portugal and Ireland
Correlation between Portugal and Ireland
50-Day Rolling Means of Correlation between Portugal and Greece
Correlation between Portugal and Greece
50-Day Rolling Means of Correlation between Spain and Ireland
Correlation between Spain and Ireland
50-Day Rolling Means of Correlation between Spain and Greece
Correlation between Spain and Greece
50-Day Rolling Means of Correlation between Ireland and Greece
Correlation between Ireland and Greece
2014-01-01
2016-01-01