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Correlation and volatility on bond markets during the EMU crisis: does the OMT change the process ?

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Abstract

This article studies the correlation and volatility transmission between the European sovereign debt markets during the period of 2008-2013. By applying a multivariate GARCH model and a flight-to-quality test, the empirical results support not only the existence of flight-to-quality from the periphery countries (Italy, Portugal, Spain, Ireland and Greece) to the pivot countries (France and Germany), but also the flight within each group. This can be explained by a new phenomenon of speculation in bond markets which didn't exist before the debt crisis. However, the estimations bring little evidence that allow us to generalize it to all markets. It seems that in terms of volatility, the pivot countries are relatively difficult to be influenced by the external turbulence. Although we prefer to believe that Europe has walked out of the sovereign debt crisis after the Outright Monetary Transaction (OMT) plan, this study doesn't bring much support for this point of view.

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1. Introduction

Understanding the volatility transmission and flight-to-quality phenomenon between sovereign debt markets is important for investors and policy makers. The transmission of volatility between different government bonds affects directly the evolution of their risk premium. For the policy makers, it can influence the cost of public debt as well as the economic decisions. This issue may be particularly important and relevant in European Monetary Union as the governments of the Member States may issue debt, but do not have the ability to monetize or to reduce their excessive long-term debt with inflationary politics. During the sovereign debt crisis, the correlation of yields between major government bonds has been from positive to negative, and this have changed the behaviors of investors. To be more specific, they have the tendency to increase their allocation to government bonds of the pivots countries, like France, Germany, given by a lower perceived risk, and decrease their allocation to government bonds of periphery countries like Greece, Spain. Therefore, an accurate modeling of this flight-to-quality phenomenon is helpful to investors for better portfolio diversifications.

Flight-to-quality and contagion are two antagonist concepts for explaining the correlation between markets. Forbes and Rigobon (2002) define the contagion as a significant increase in cross-market linkages after a shock to one country (or group of countries). In this study, we define the flight-to-quality as a significant decrease in cross-market linkages after a shock to a group of countries. Furthermore, in accordance with Baur and Lucey (2006), we define positive and negative contagion as well as flight-from-quality in the Table 1.

Table 1.1 Overview flight-to-quality, flight-from-quality and contagion

	Correlation falling	Correlation rising
Periphery Countries' Bond markets falling	Flight-to-quality	(Negative) Contagion
Periphery Countries' Bond markets rising	Flight-from-quality	(Positive) Contagion
Pivot Countries' Bond markets falling	Flight-from-quality	(Negative) Contagion
Pivot Countries' Bond markets rising	Flight-to-quality	(Positive) Contagion

This paper has three objectives. First of all, it proposes a formal test of the phenomenon of flight-to-quality among major bond markets in the euro zone. By using this test and a trivariate AR(1)-VECH-GARCH(1,1) model, it examines whether it exist a significant decline of conditional correlations between bond yields of the countries in crisis and those who were identified by investors as refuge. Next, it questions about the aspect of speculation during the flight-to-quality. More precisely, it examines the interdependence of conditional variances between bond yields in different markets by adding two lagged effects of the source market to the original trivariate AR(1)-VECH-GARCH(1,1) model. We could expect particularly an increase in the perception of risk (volatility) and conditional variances on the markets in crisis, and also a decrease in conditional variances on the refuge markets where the following scenario that an unavoidable decline of the high return yields of the bonds becomes increasingly clear in the eyes of investors. Specifically, it is to test a possible change of sign on the parameters associated with the transmission of volatility in the trivariate AR(1)-VECH-GARCH(1,1) model. Finally we examine the impact of the OMT decided in September 2012, on both the variances and conditional correlations between bond markets and parameters of transmission of volatility. The central question here is whether this decision has marked the end of the phenomenon of flight-to-quality, whether it is the beginning of a recorrelation of the markets and somehow whether it is the end of the sovereign debt crisis for the majority of investors. Therefore, we test in the other words the faith of the investors in the efficiency of a "Draghi Put" offered by the OMT.

This paper is organized as follows. Section 2 describes the data and presents the trivariate VECH models which support the different tests of hypotheses. Section 3 presents not only the test of flight-to-quality and contagion but also the tests of conditional variances of bond yields: the tests of comparison in each sub period and the tests on the parameters of volatility transmission. Section 4 summarizes our results and present our vision on the process of recovery from crisis and efficiency of "Draghi Put".

2. Data and model

This paper uses daily time series from January 2008 to September 2013. We use the total return index of 10-years government bond (Source: Datastream) of seven major countries in the European Monetary Union including France (FR), Germany (GER), Italy (IT), Portugal (PT), Spain (ES), Ireland (IR), and Greece (GR). Moreover, France and Germany are classified as pivot countries, and Italy, Portugal, Spain, Ireland and Greece are classified as periphery countries. We choose two important dates to separate the time series into three sub-periods, December 8th 2009, the day when the government bond of Greece was downgraded to BBB by Fitch, which is always considered as the beginning of the sovereign debt crisis, and September 12th 2012, when the OMT plan was approved by the EMU members which could be, to some extent, regarded as the end of the European debt crisis.

Figure 1: Total Return Index, based 100, source Datastream.

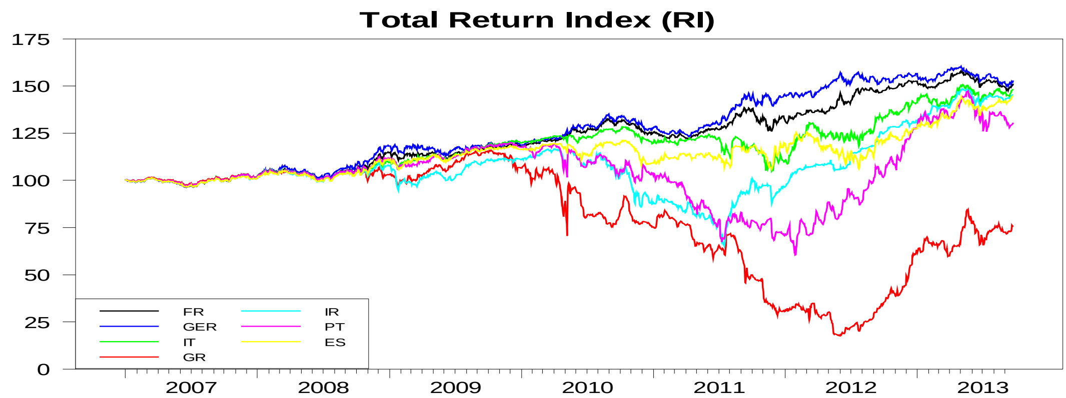
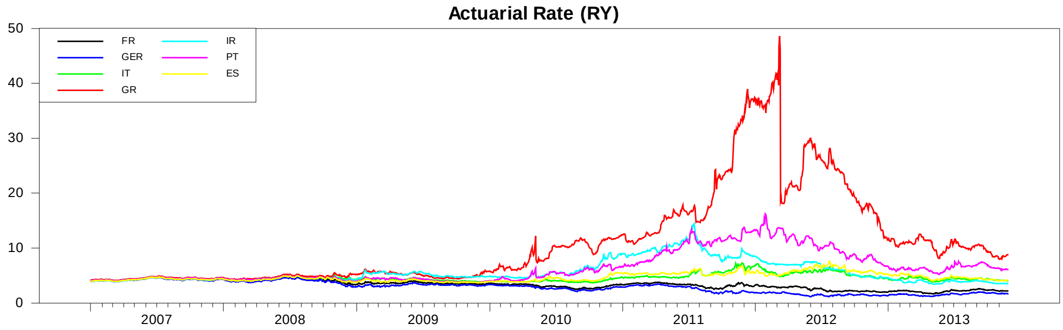


Figure 2: 10 Years Bond Return Yield, source Datastream.



The econometric model that serves to support the empirical evaluation based on the following two assumptions. The process followed by the daily bond yields (variations of log RI) is of type AR (1) with the error term noted $\varepsilon_{i,t}$ of type GARCH. In order to stay in the frame of EMH (Efficient Market Hypothesis), we suppose that the interdependence between bond yields goes only through second conditional moments, The variance-covariance matrix is apprehended by a parsimonious VECH formulation and it is sufficient for the implementation of the tests of contagion / flight to quality and those on the volatility interdependence (tests of volatility spillover).

$$R_{i,t} = \mu + \varphi R_{i,t-1} + \varepsilon_{i,t} \quad i = 1, \dots, 7 \qquad (1)$$

The status and interpretation to error term $\varepsilon_{i,t}$ is essential. Note first that the autoregressive form of the conditional mean equation of bond yields allows us to consider a gradual diffusion but not an instantaneous positive or negative shocks to bond yields. So we have next two possible and complementary readings of the variable $\varepsilon_{i,t}$.

In a context of information efficiency, the variable $\varepsilon_{i,t}$ reflects in principle all important "news" to anticipate rationally the bond yields over a period beginning at the current time t and ending at a future date corresponding to a horizon for each investor. The expected returns depend on the expected future price and the probable value of future payments (coupon or principal). The rational investors should actually anticipate all future equilibrium in the bond market. They are therefore sensitive to any information on future demand for securities, including those from the central bank (Securities Markets Programme, Outright Monetary Transactions).

The variable $\varepsilon_{i,t}$ should also include all the information relating to funding needs and the present and future supply of securities. The most critical information are probably those that explicitly focus on the solvency of the sovereign issuer, especially all the variables involved in the mechanisms of debt sustainability, such as future nominal growth, primary balance, debt to GDP ratio, institutional rescue plan. We should also understand that the prices and bond yields should also integrate a risk premium of volatility the same as it is determined by the market equilibrium.

In contrast, the $\varepsilon_{i,t}$ in our model may also reflect some more speculative behaviors such as formation of temporary bubbles and the triggering by mimetic behaviors (noise trading). It may be related to non-rational expectations as well.

We use a trivariate GARCH (1,1) model to quantify the transmission of volatility and flight-to-quality phenomenon. Bollerslev, Engle and Wooldridge (1988) present one simplified formulation of the multivariate GARCH model, the diagonal VECH model. Based on this formulation, we estimate the coefficient of volatility transmission by adding four parameters d_{11}, d_{12}, d_{31} and d_{32}, which take into account the effects of lagged conditional variances of the source country. Therefore, in this trivariate diagonal VECH model, the conditional variance equations become:

$$h_{11,t} = c_1 + a_1 \varepsilon^2_{1,t-1} + b_1 h_{11,t-1} + d_{11} D_1 h_{22,t-1} + d_{12} D_2 h_{22,t-1} \quad (2)$$
$$h_{22,t} = c_2 + a_2 \varepsilon^2_{2,t-1} + b_2 h_{22,t-1} \quad (3)$$
$$h_{33,t} = c_3 + a_3 \varepsilon^2_{3,t-1} + b_3 h_{33,t-1} + d_{31} D_1 h_{22,t-1} + d_{32} D_2 h_{22,t-1} \quad (4)$$
$$h_{ij,t} = c_{ij} + a_{ij} \varepsilon_{i,t-1} \varepsilon_{j,t-1} + b_{ij} h_{ij,t-1} \quad (5)$$

where D_1 and D_2 are two dummy variables that separate the two sub estimated periods, $D_1=1$ and $D_2=0$ if before the rupture date, $D_1=0$ and $D_2=1$ otherwise, $h_{ii,t}$ is the conditional variance of each market at time t, $\varepsilon^2_{ii,t-1}$ is the one period lagged ARCH factor, $h_{ii,t-1}$ is the one period lagged GARCH factor, $h_{22,t-1}$ is the one period lagged conditional variance of market 2 (source market). d_{11}, d_{12}, d_{31} and d_{32} are four estimations of the volatility transmission from market 2 to market 1 and 3 in two different sub periods. $\varepsilon_{i,t}$ is a white noise that $E(\varepsilon_{i,t}) = 0$ and $V(\varepsilon_{i,t}/I_{t-1}) = h_{ii,t}$ The rest elements are the same as presented above. The correlation coefficient is defined as follows:

$$\rho_{ij,t} = \frac{h_{ij,t}}{\sqrt{h_{ii,t}}\sqrt{h_{jj,t}}}$$

where i, j=1,2,3 and $i \neq j$, $\rho_{ij,t}$ is the essential factor in this methodology because it represents the conditional correlation between returns of different government bonds.

The parameters of the trivariate GARCH model are estimated by the method of maximum log-likelihood. Precisely, with algorithm of 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 of BHHH to estimate the GARCH model. This calculation is programmed in Winrats version 8.1.

3. Principals of tests on second conditional moment

To test whether the means of conditional variances across period have significantly changed, we apply the test of Welch. Published by Bernard Lewis Welch (1947), this test is an approached solution of the Behrens-Fisher problem. The objective of Welch test is to determine whether or not statistically there is an equality of means of two sub-samples in the case of their variances are different. In this sense, it is a more robust alternative then the student test when the condition on the variances is not respected. Therefore, the hypothesis is constructed :

$$\begin{cases} H_0: \mu_1 = \mu_2 \\ H_1: \mu_1 \neq \mu_2 \end{cases}$$

The statistic of this test proposed by Welch is:

$$\mathrm{t} = \frac{\mu_1 - \mu_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

Where μ_i is the mean of the simple, S_i the variance and N_i the number of observations. The degree of freedom ν associated with this variance estimate is approximated using the Welch–Satterthwaite equation:

$$\nu \approx \frac{\left(\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}\right)^2}{\frac{\left(\frac{S_1^2}{N_1}\right)^2}{N_1 - 1} + \frac{\left(\frac{S_2^2}{N_2}\right)^2}{N_2 - 1}}$$

It's important to notice that the degree of freedom is associated with the i^{th} variance estimate. The statistic t follows the distribution of student with the degree of freedom ν.

In the flight to quality test, we test the hypotheses of structural changes of correlati on coefficients across the tranquil and turmoil 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 the bond. More specifically, compared to the estimation during a stable period, the correlation coefficients are over estimated during a turmoil period. In our study, the correlations are conditional and dynamic. Therefore, we modify the adjustment formula of correlation coefficient proposed by Forbes and Rigobon (2002) into the following formula:

$$\rho_{i,p}^* = \frac{\rho_{i,p}}{\sqrt{1 + \delta(1 - \rho_{i,p}^2)}}$$

Where $\delta = \frac{h^T}{h^S} - 1$ is the relative increase in the variance of the source country across stable period and turmoil periods. $\rho_{i,p}$ is the average of dynamic conditional correlations during period *p*, *p = (s, t)*, while *s* and *t* indicate the stable period and turmoil period. We should note that the stable period is a relative concept. It will be presented as pre-crisis period and the post-OMT period in our text.

With the adjusted correlation coefficients, we apply the test proposed by Collins and Biekpe (2003) to detect the existence of flight-to-quality across stable period and turmoil period.

The Student test is:

$$\begin{cases} H_0: \rho_S^* = \rho_T^* \\ H_1: \rho_S^* > \rho_T^* \end{cases}$$

Where ρ_T^* is the adjusted correlation coefficient in turmoil period and ρ_S^* is the adjusted correlation coefficient in stable period.

The statistic of the student test applied by Collins and Biekpe (2003) is:

$$t = (\rho_S^* - \rho_T^*)\sqrt{\frac{n_S + n_T - 4}{1 - (\rho_S^* - \rho_T^*)^2}}$$

where $t \sim T_{(n_S+n_T-4)}$.

If we accept H_1, it means that the correlation coefficient across two periods has significantly decreased during the turmoil period, that is an evidence of the flight-to-quality phenomenon.

4. Results

Before the presentation of the results of the tests, table 4.1 and table 4.2 present the statistics of the cumulative yields and the conditional variances in the three sub periods that we analyze. We note that the conditional variances which are presented in table 4.2 are obtained from a univariate GARCH model.

The principal results from our different statistical tests can be summarized and interpreted as follows. Welch test on the comparison of the average conditional variances for the three sub periods (pre-crisis, crisis, post-OMT) clearly show that for Germany and France, the bond markets are less volatile during crisis than before the crisis. Without surprise, the formal adoption of the OMT in September 2012 led to a further decrease in the average level of conditional variances, it's a synonyms for investors to have less risk on bond yields.

Conversely, for Greece, the conditional variance of returns increases sharply during the crisis. It starts to drop from the implementation of the OMT. However, it doesn't find its pre-crisis levels. We find some evolution profiles for Spain, Italy and Portugal.

The situation of the Irish bond market is unique among the seven cases studied. The conditional variance of returns increases sharply during the crisis, and after the OMT, we find this level of risk is even lower than the pre-crisis period.

Table 4.1 Cumulative Period Yield and Ranking

Market	Pre-crisis Period	Crisis Period	Post-OMT Period
FR	0.1809 (3)	0.2346 (2)	0.0257 (6)
GER	0.1892 (1)	0.2541 (1)	0.0083 (7)
ES	0.1699 (5)	0.0352 (5)	0.1819 (4)
GR	0.0739 (7)	-0.7120 (7)	1.4148 (1)
IT	0.1873 (2)	0.1029 (3)	0.1123 (5)
PT	0.0929 (6)	0.1019 (4)	0.1898 (3)
IR	0.1773 (4)	-0.1056 (6)	0.2207 (2)

Table 4.2 Average (m) Conditional Variances and Ranking

Market	Pre-crisis Period (m1)	Crisis Period (m2)	Post-OMT Period (m3)
FR	0.15425(1)	0.14609(1)	0.09631(1)
GER	0.20356(5)	0.16743(2)	0.11961(2)
ES	0.18955(4)	0.57506(3)	0.41559(4)
GR	0.94434(7)	4.63899(7)	2.75178(7)
IT	0.16967(2)	0.62821(4)	0.46088(5)
PT	0.17390(3)	1.65644(6)	1.32545(6)
IR	0.26755(6)	1.08241(5)	0.19276(3)

Figure 3: Three Patterns of Average Conditional Variances of Daily Returns.

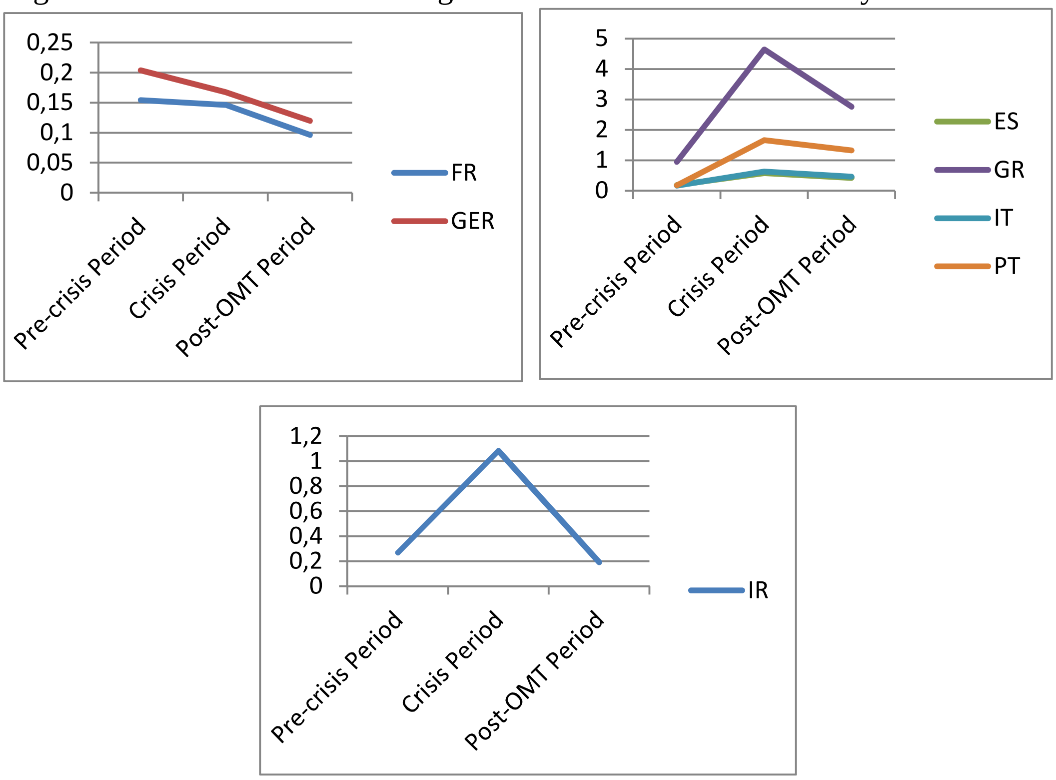


Table 4.3 Results of tests of Welch

Market	Pre-crisis (m1) with Crisis (m2)	Crisis (m2) with Post-OMT (m3)	Pre-crisis (m1) with Post-OMT (m3)	Conclusion
FR	m1>m2**	m2>m3**	m1>m3**	m1>m2>m3
GER	m1>m2**	m2>m3**	m1>m3**	
ES	m1<m2**	m2>m3**	m1<m3**	m2>m3>m1
GR	m1<m2**	m2>m3**	m1<m3**	
IT	m1<m2**	m2>m3**	m1<m3**	
PT	m1<m2**	m2>m3**	m1<m3**	
IR	m1<m2**	m2>m3**	m1>m3**	m2>m1>m3

Notes: ** and * indicate statistically significance at the 5% and 10% level, respectively.

Regarding the tests on parameters of volatility transmission (d_{11}, d_{12} in equation (2) and d_{31}, d_{32} in equation (4)) two findings emerge from our estimations. There are few evidence that support a global phenomenon of conditional volatility transmission between markets. However, there is a significant relationship between the Greek and Irish bond markets during the crisis period where the increase of the conditional variance in the Greek market has clearly contributed to reduce the risk of volatility seen in the Irish market. Therefore, we could say there is a phenomenon of the eviction of volatility between the two countries.

The tests on the evolution of conditional covariance between bond markets show that the logic of the flight to quality is predominant at the beginning of the sovereign debt crisis (period 2 in our estimations).There is systematically a decrease in conditional correlations of bond yields for almost all pairs of markets studied. This is observed in both cross-country correlations of different groups (periphery to pivot countries) and correlations between countries of the same group.

With the exception of the pair country France-Germany, the conditional correlations of the other markets have neither increased significantly from September 2012 nor after the plan OMT by the ECB. Therefore, there isn't a general beginning of a re-correlation of bond markets, but rather a stabilization of conditional correlations at levels close to those estimated in the previous period (period 2 in our study).

Table 4.4 Average Level of Conditional Correlations in Different Period

Market Trio	Market Pair	Pre-crisis to Crisis		Crisis to Post-OMT	
FR-GR-GER	FR-GR	0.56908	0.09207	0.01156	0.01399
	FR-GER	0.95018	0.70936	0.68354	0.78483
	GR-GER	0.43865	0.00683	-0.10285	-0.09220
ES-GR-GER	ES-GR	0.49877	0.15961	0.30176	0.25930
	ES-GER	0.85981	0.06770	-0.10759	-0.12006
	GR-GER	0.33690	0.03126	-0.12537	-0.12193
IT-GR-GER	IR-GR	0.80993	0.31709	0.24036	0.14662
	IR-GER	0.72849	0.08425	-0.02687	-0.03691
	GR-GER	0.49295	-0.03772	-0.10493	-0.10292
PT-GR-GER	PT-GR	0.73662	0.24290	0.31767	0.33931
	PT-GER	0.53073	0.03304	-0.08860	-0.15920
	GR-GER	0.40280	-0.00796	-0.11682	-0.10372
IR-GR-GER	IR-GR	0.74533	0.35567	0.22491	0.24333
	IR-GER	0.75001	0.03396	-0.02555	-0.04147
	GR-GER	0.62031	-0.09997	-0.12810	-0.12208

Table 4.5 Results of Flight-to-Quality (FTQ) Tests for Major Country Pairs

	Pre-crisis to Crisis			Crisis to Post-OMT		
	Alternative Hypothesis	P-value	Result	Alternative Hypothesis	P-value	Result
FR-GR	$\rho_S^* > \rho_T^*$	0.01	FTQ	$\rho_S^* < \rho_T^*$	0.90	StillCrisis
FR-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.01	Out of Crisis
GR-GER	$\rho_S^* > \rho_T^*$	0.04	FTQ	$\rho_S^* < \rho_T^*$	0.62	StillCrisis
ES-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.17	StillCrisis
ES-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.43	StillCrisis
IT-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.48	StillCrisis
IT-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.32	StillCrisis
PT-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.49	StillCrisis
PT-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.27	StillCrisis
IR-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.45	StillCrisis
IR-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.48	StillCrisis

5. Conclusion

Our multivariate GARCH modeling of bond yields of major countries in the euro area over the period January 2008 - September 2013 brings several important and original results.

Concerning the conditional variance of returns, that is to say, the evaluation of risks perceived by investors, three patterns of evolution appear clearly. As for France and Germany, their bond yields are less volatile since the beginning of the sovereign debt crisis (period 2 in modeling) and the implementation of the OMT has accentuated this trend. For the Greek, Spanish, Italian and Portuguese bond markets, the conditional variances and perceived risks rise sharply during the crisis before falling with the implementation of the OMT. However, they don't return to the pre-crisis period levels. The Irish market has an intermediate evolution pattern with a peak of volatility during the crisis and then finish by a risk level lower than pre-crisis period.

The results also show that there is little evidence of volatility spillover between markets, with the exception of the link between the Greek market and the Irish market spotted during crisis.

The tests on conditional correlations of returns clearly show that the investors have followed a generalized logic of flight to quality since the beginning of the debt crisis. Therefore, we find a decrease in conditional correlations of bond yields. The implementation of the OMT and "Draghi put" had only the effect of blocking this process of decline of the correlations between markets. The French and German markets are the only two who return to their pre-crisis correlation level.

Our empirical results tend to support the argument that during the sovereign debt crisis the German and French bond markets have made an ideal investment haven for investors. The logic of the flight to quality and the protection against sovereign risk have contributed to a decline in interest rate the same as an increase of bond return.

Without doubt, the decrease in conditional variances of these returns also fueled more speculative strategies based on optimization of the return-risk pair in bond portfolios management.

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Flight-to-quality and contagion are two antagonist concepts for explaining the correlation between markets. Forbes and Rigobon (2002) define the contagion as a significant increase in cross-market linkages after a shock to one country (or group of countries). In this study, we define the flight-to-quality as a significant decrease in cross-market linkages after a shock to a group of countries. Furthermore, in accordance with Baur and Lucey (2006), we define positive and negative contagion as well as flight-from-quality in the Table 1.

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Pivot Countries' Bond markets falling	Flight-from-quality	(Negative) Contagion
Pivot Countries' Bond markets rising	Flight-to-quality	(Positive) Contagion

This paper has three objectives. First of all, it proposes a formal test of the phenomenon of flight-to-quality among major bond markets in the euro zone. By using this test and a trivariate AR(1)-VECH-GARCH(1,1) model, it examines whether it exist a significant decline of conditional correlations between bond yields of the countries in crisis and those who were identified by investors as refuge. Next, it questions about the aspect of speculation during the flight-to-quality. More precisely, it examines the interdependence of conditional variances between bond yields in different markets by adding two lagged effects of the source market to the original trivariate AR(1)-VECH-GARCH(1,1) model. We could expect particularly an increase in the perception of risk (volatility) and conditional variances on the markets in crisis, and also a decrease in conditional variances on the refuge markets where the following scenario that an unavoidable decline of the high return yields of the bonds becomes increasingly clear

in the eyes of investors. Specifically, it is to test a possible change of sign on the parameters associated with the transmission of volatility in the trivariate AR(1)-VECH-GARCH(1,1) model. Finally we examine the impact of the OMT decided in September 2012, on both the variances and conditional correlations between bond markets and parameters of transmission of volatility. The central question here is whether this decision has marked the end of the phenomenon of flight-to-quality, whether it is the beginning of a recorrelation of the markets and somehow whether it is the end of the sovereign debt crisis for the majority of investors. Therefore, we test in the other words the faith of the investors in the efficiency of a "Draghi Put" offered by the OMT.
This paper is organized as follows. Section 2 describes the data and presents the trivariate VECH models which support the different tests of hypotheses. Section 3 presents not only the test of flight-to-quality and contagion but also the tests of conditional variances of bond yields: the tests of comparison in each sub period and the tests on the parameters of volatility transmission. Section 4 summarizes our results and present our vision on the process of recovery from crisis and efficiency of "Draghi Put".

2. Data and model

This paper uses daily time series from January 2008 to September 2013. We use the total return index of 10-years government bond (Source: Datastream) of seven major countries in the European Monetary Union including France (FR), Germany (GER), Italy (IT), Portugal (PT), Spain (ES), Ireland (IR), and Greece (GR). Moreover, France and Germany are classified as pivot countries, and Italy, Portugal, Spain, Ireland and Greece are classified as periphery countries. We choose two important dates to separate the time series into three sub-periods, December 8th 2009, the day when the government bond of Greece was downgraded to BBB by Fitch, which is always considered as the beginning of the sovereign debt crisis, and September 12th 2012, when the OMT plan was approved by the EMU members which could be, to some extent, regarded as the end of the European debt crisis.

Figure 1: Total Return Index, based 100, source Datastream.

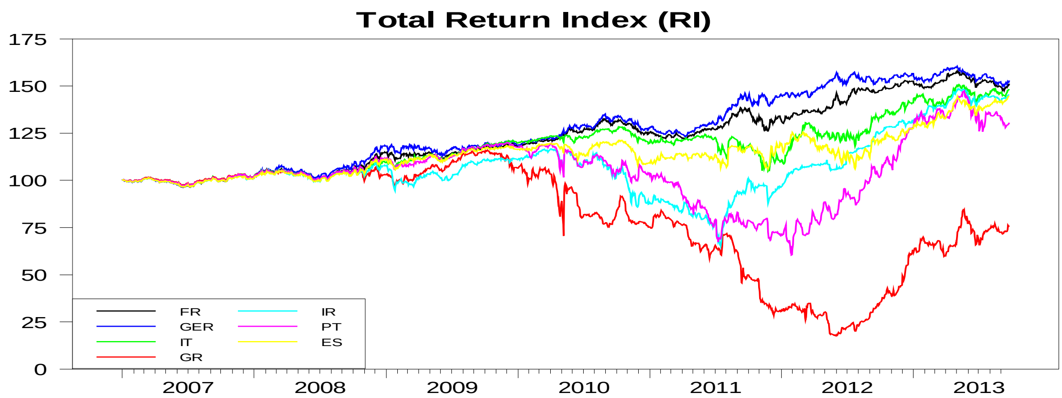
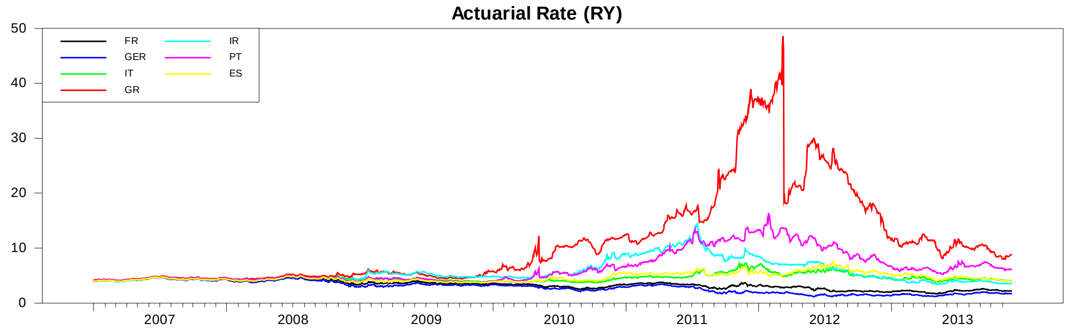


Figure 2: 10 Years Bond Return Yield, source Datastream.



The econometric model that serves to support the empirical evaluation based on the following two assumptions. The process followed by the daily bond yields (variations of log RI) is of type AR (1) with the error term noted $\varepsilon_{i,t}$ of type GARCH. In order to stay in the frame of EMH (Efficient Market Hypothesis), we suppose that the interdependence between bond yields goes only through second conditional moments, The variance-covariance matrix is apprehended by a parsimonious VECH formulation and it is sufficient for the implementation of the tests of contagion / flight to quality and those on the volatility interdependence (tests of volatility spillover).

$$R_{i,t} = \mu + \varphi R_{i,t-1} + \varepsilon_{i,t} \quad i = 1, \ldots, 7 \qquad (1)$$

The status and interpretation to error term $\varepsilon_{i,t}$ is essential. Note first that the autoregressive form of the conditional mean equation of bond yields allows us to consider a gradual diffusion but not an instantaneous positive or negative shocks to bond yields. So we have next two possible and complementary readings of the variable $\varepsilon_{i,t}$.

In a context of information efficiency, the variable $\varepsilon_{i,t}$ reflects in principle all important "news" to anticipate rationally the bond yields over a period beginning at the current time t and ending at a future date corresponding to a horizon for each investor. The expected returns depend on the expected future price and the probable value of future payments (coupon or principal). The rational investors should actually anticipate all future equilibrium in the bond market. They are therefore sensitive to any information on future demand for securities, including those from the central bank (Securities Markets Programme, Outright Monetary Transactions).

The variable $\varepsilon_{i,t}$ should also include all the information relating to funding needs and the present and future supply of securities. The most critical information are probably those that explicitly focus on the solvency of the sovereign issuer, especially all the variables involved in the mechanisms of debt sustainability, such as future nominal growth, primary balance, debt to GDP ratio, institutional rescue plan. We should also understand that the prices and bond yields should also integrate a risk premium of volatility the same as it is determined by the market equilibrium.

In contrast, the $\varepsilon_{i,t}$ in our model may also reflect some more speculative behaviors such as formation of temporary bubbles and the triggering by mimetic behaviors (noise trading). It may be related to non-rational expectations as well.

We use a trivariate GARCH (1,1) model to quantify the transmission of volatility and flight-to-quality phenomenon. Bollerslev, Engle and Wooldridge (1988) present one simplified formulation of the multivariate GARCH model, the diagonal VECH model. Based on this formulation, we estimate the coefficient of volatility transmission by adding four parameters d_{11}, d_{12}, d_{31} and d_{32}, which take into account the effects of lagged conditional variances of the source country. Therefore, in this trivariate diagonal VECH model, the conditional variance equations become:

$$h_{11,t} = c_1 + a_1\varepsilon^2_{1,t-1} + b_1 h_{11,t-1} + d_{11}D_1 h_{22,t-1} + d_{12}D_2 h_{22,t-1} \quad (2)$$
$$h_{22,t} = c_2 + a_2\varepsilon^2_{2,t-1} + b_2 h_{22,t-1} \quad (3)$$
$$h_{33,t} = c_3 + a_3\varepsilon^2_{3,t-1} + b_3 h_{33,t-1} + d_{31}D_1 h_{22,t-1} + d_{32}D_2 h_{22,t-1} \quad (4)$$
$$h_{ij,t} = c_{ij} + a_{ij}\varepsilon_{i,t-1}\varepsilon_{j,t-1} + b_{ij} h_{ij,t-1} \quad (5)$$

where D_1 and D_2 are two dummy variables that separate the two sub estimated periods, $D_1=1$ and $D_2=0$ if before the rupture date, $D_1=0$ and $D_2=1$ otherwise, $h_{ii,t}$ is the conditional variance of each market at time t, $\varepsilon^2_{ii,t-1}$ is the one period lagged ARCH factor, $h_{ii,t-1}$ is the one period lagged GARCH factor, $h_{22,t-1}$ is the one period lagged conditional variance of market 2 (source market). d_{11}, d_{12}, d_{31} and d_{32} are four estimations of the volatility transmission from market 2 to market 1 and 3 in two different sub periods. $\varepsilon_{i,t}$ is a white noise that $E(\varepsilon_{i,t}) = 0$ and $V(\varepsilon_{i,t}/I_{t-1}) = h_{ii,t}$ The rest elements are the same as presented above. The correlation coefficient is defined as follows:

$$\rho_{ij,t} = \frac{h_{ij,t}}{\sqrt{h_{ii,t}}\sqrt{h_{jj,t}}}$$

where i, j=1,2,3 and $i \neq j$, $\rho_{ij,t}$ is the essential factor in this methodology because it represents the conditional correlation between returns of different government bonds.

The parameters of the trivariate GARCH model are estimated by the method of maximum log-likelihood. Precisely, with algorithm of 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 of BHHH to estimate the GARCH model. This calculation is programmed in Winrats version 8.1.

3. Principals of tests on second conditional moment

To test whether the means of conditional variances across period have significantly changed, we apply the test of Welch. Published by Bernard Lewis Welch (1947), this test is an approached solution of the Behrens-Fisher problem. The objective of Welch test is to determine whether or not statistically there is an equality of means of two sub-samples in the case of their variances are different. In this sense, it is a more robust alternative then the student test when the condition on the variances is not respected.

Therefore, the hypothesis is constructed :

$$\begin{cases} H_0: \mu_1 = \mu_2 \\ H_1: \mu_1 \neq \mu_2 \end{cases}$$

The statistic of this test proposed by Welch is:

$$\mathrm{t} = \frac{\mu_1 - \mu_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

Where μ_i is the mean of the simple, S_i the variance and N_i the number of observations. The degree of freedom ν associated with this variance estimate is approximated using the Welch–Satterthwaite equation:

$$\nu \approx \frac{\left(\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}\right)^2}{\frac{\left(\frac{S_1^2}{N_1}\right)^2}{N_1 - 1} + \frac{\left(\frac{S_2^2}{N_2}\right)^2}{N_2 - 1}}$$

It's important to notice that the degree of freedom is associated with the i^th^ variance estimate. The statistic t follows the distribution of student with the degree of freedom ν.

In the flight to quality test, we test the hypotheses of structural changes of correlati
on coefficients across the tranquil and turmoil 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 the bond. More specifically, compared to the estimation during a stable period, the correlation coefficients are over estimated during a turmoil period. In our study, the correlations are conditional and dynamic. Therefore, we modify the adjustment formula of correlation coefficient proposed by Forbes and Rigobon (2002) into the following formula:

$$\rho_{i,p}^* = \frac{\rho_{i,p}}{\sqrt{1 + \delta(1 - \rho_{i,p}^2)}}$$

Where $\delta = \frac{h^T}{h^S} - 1$ is the relative increase in the variance of the source country across stable period and turmoil periods. $\rho_{i,p}$ is the average of dynamic conditional correlations during period *p*, *p* = *(s, t)*, while *s* and *t* indicate the stable period and turmoil period. We should note that the stable period is a relative concept. It will be presented as pre-crisis period and the post-OMT period in our text.

With the adjusted correlation coefficients, we apply the test proposed by Collins and Biekpe (2003) to detect the existence of flight-to-quality across stable period and turmoil period.

The Student test is:

$$\begin{cases} H_0: \rho_S^* = \rho_T^* \\ H_1: \rho_S^* > \rho_T^* \end{cases}$$

Where ρ_T^* is the adjusted correlation coefficient in turmoil period and ρ_S^* is the adjusted correlation coefficient in stable period.

The statistic of the student test applied by Collins and Biekpe (2003) is:

$$t = (\rho_S^* - \rho_T^*)\sqrt{\frac{n_S + n_T - 4}{1 - (\rho_S^* - \rho_T^*)^2}}$$

where $t \sim T_{(n_S+n_T-4)}$.

If we accept H_1, it means that the correlation coefficient across two periods has significantly decreased during the turmoil period, that is an evidence of the flight-to-quality phenomenon.

4. Results

Before the presentation of the results of the tests, table 4.1 and table 4.2 present the statistics of the cumulative yields and the conditional variances in the three sub periods that we analyze. We note that the conditional variances which are presented in table 4.2 are obtained from a univariate GARCH model.

The principal results from our different statistical tests can be summarized and interpreted as follows. Welch test on the comparison of the average conditional variances for the three sub periods (pre-crisis, crisis, post-OMT) clearly show that for Germany and France, the bond markets are less volatile during crisis than before the crisis. Without surprise, the formal adoption of the OMT in September 2012 led to a further decrease in the average level of conditional variances, it's a synonyms for investors to have less risk on bond yields.

Conversely, for Greece, the conditional variance of returns increases sharply during the crisis. It starts to drop from the implementation of the OMT. However, it doesn't find its pre-crisis levels. We find some evolution profiles for Spain, Italy and Portugal.

The situation of the Irish bond market is unique among the seven cases studied. The conditional variance of returns increases sharply during the crisis, and after the OMT, we find this level of risk is even lower than the pre-crisis period.

Table 4.1 Cumulative Period Yield and Ranking

Market	Pre-crisis Period	Crisis Period	Post-OMT Period
FR	0.1809 (3)	0.2346 (2)	0.0257 (6)
GER	0.1892 (1)	0.2541 (1)	0.0083 (7)
ES	0.1699 (5)	0.0352 (5)	0.1819 (4)
GR	0.0739 (7)	-0.7120 (7)	1.4148 (1)
IT	0.1873 (2)	0.1029 (3)	0.1123 (5)
PT	0.0929 (6)	0.1019 (4)	0.1898 (3)
IR	0.1773 (4)	-0.1056 (6)	0.2207 (2)

Table 4.2 Average (m) Conditional Variances and Ranking

Market	Pre-crisis Period (m1)	Crisis Period (m2)	Post-OMT Period (m3)
FR	0.15425(1)	0.14609(1)	0.09631(1)
GER	0.20356(5)	0.16743(2)	0.11961(2)
ES	0.18955(4)	0.57506(3)	0.41559(4)
GR	0.94434(7)	4.63899(7)	2.75178(7)
IT	0.16967(2)	0.62821(4)	0.46088(5)
PT	0.17390(3)	1.65644(6)	1.32545(6)
IR	0.26755(6)	1.08241(5)	0.19276(3)

Figure 3: Three Patterns of Average Conditional Variances of Daily Returns.

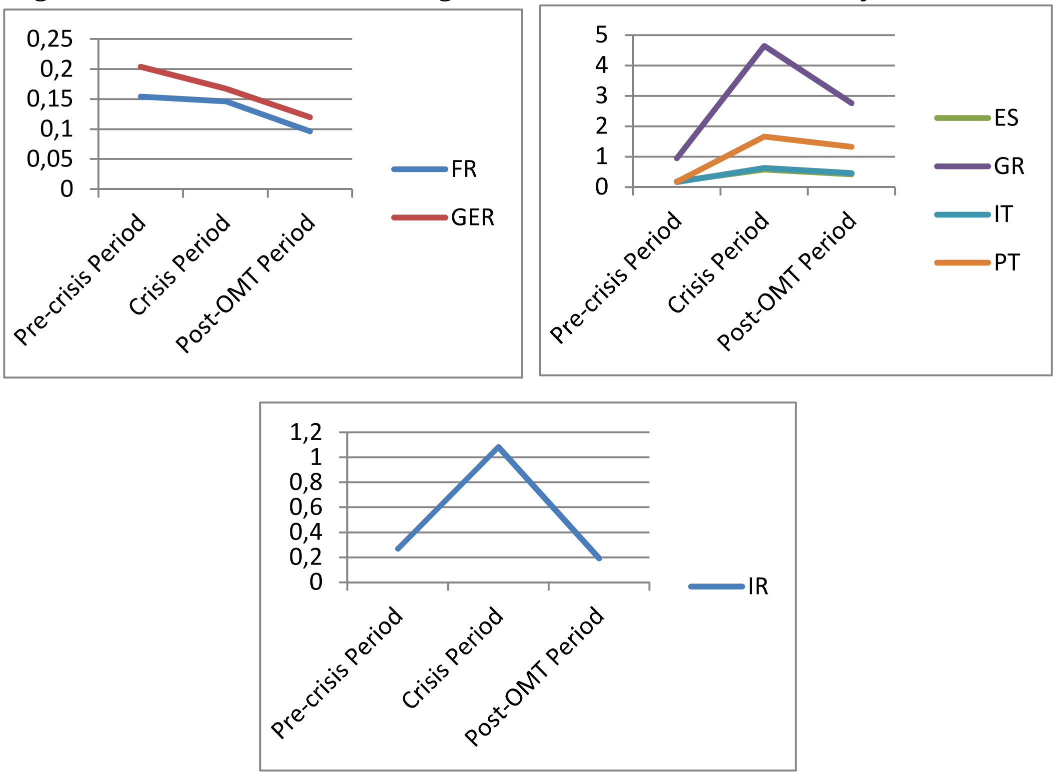


Table 4.3 Results of tests of Welch

Market	Pre-crisis (m1) with Crisis (m2)	Crisis (m2) with Post-OMT (m3)	Pre-crisis (m1) with Post-OMT (m3)	Conclusion
FR	m1>m2**	m2>m3**	m1>m3**	m1>m2>m3
GER	m1>m2**	m2>m3**	m1>m3**	
ES	m1<m2**	m2>m3**	m1<m3**	m2>m3>m1
GR	m1<m2**	m2>m3**	m1<m3**	
IT	m1<m2**	m2>m3**	m1<m3**	
PT	m1<m2**	m2>m3**	m1<m3**	
IR	m1<m2**	m2>m3**	m1>m3**	m2>m1>m3

Notes: ** and * indicate statistically significance at the 5% and 10% level, respectively.

Regarding the tests on parameters of volatility transmission (d_{11}, d_{12} in equation (2) and d_{31}, d_{32} in equation (4)) two findings emerge from our estimations. There are few evidence that support a global phenomenon of conditional volatility transmission between markets. However, there is a significant relationship between the Greek and Irish bond markets during the crisis period where the increase of the conditional variance in the Greek market has clearly contributed to reduce the risk of volatility seen in the Irish market. Therefore, we could say there is a phenomenon of the eviction of volatility between the two countries.
The tests on the evolution of conditional covariance between bond markets show that the logic of the flight to quality is predominant at the beginning of the sovereign debt crisis (period 2 in our estimations).There is systematically a decrease in conditional correlations of bond yields for almost all pairs of markets studied. This is observed in both cross-country correlations of different groups (periphery to pivot countries) and correlations between countries of the same group.
With the exception of the pair country France-Germany, the conditional correlations of the other markets have neither increased significantly from September 2012 nor after the plan OMT by the ECB. Therefore, there isn't a general beginning of a re-correlation of bond markets, but rather a stabilization of conditional correlations at levels close to those estimated in the previous period (period 2 in our study).

Table 4.4 Average Level of Conditional Correlations in Different Period

Market Trio	Market Pair	Pre-crisis to Crisis		Crisis to Post-OMT	
FR-GR-GER	FR-GR	0.56908	0.09207	0.01156	0.01399
	FR-GER	0.95018	0.70936	0.68354	0.78483
	GR-GER	0.43865	0.00683	-0.10285	-0.09220
ES-GR-GER	ES-GR	0.49877	0.15961	0.30176	0.25930
	ES-GER	0.85981	0.06770	-0.10759	-0.12006
	GR-GER	0.33690	0.03126	-0.12537	-0.12193
IT-GR-GER	IR-GR	0.80993	0.31709	0.24036	0.14662
	IR-GER	0.72849	0.08425	-0.02687	-0.03691
	GR-GER	0.49295	-0.03772	-0.10493	-0.10292
PT-GR-GER	PT-GR	0.73662	0.24290	0.31767	0.33931
	PT-GER	0.53073	0.03304	-0.08860	-0.15920
	GR-GER	0.40280	-0.00796	-0.11682	-0.10372
IR-GR-GER	IR-GR	0.74533	0.35567	0.22491	0.24333
	IR-GER	0.75001	0.03396	-0.02555	-0.04147
	GR-GER	0.62031	-0.09997	-0.12810	-0.12208

Table 4.5 Results of Flight-to-Quality (FTQ) Tests for Major Country Pairs

	Pre-crisis to Crisis			Crisis to Post-OMT		
	Alternative Hypothesis	P-value	Result	Alternative Hypothesis	P-value	Result
FR-GR	$\rho_S^* > \rho_T^*$	0.01	FTQ	$\rho_S^* < \rho_T^*$	0.90	StillCrisis
FR-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.01	Out of Crisis
GR-GER	$\rho_S^* > \rho_T^*$	0.04	FTQ	$\rho_S^* < \rho_T^*$	0.62	StillCrisis
ES-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.17	StillCrisis
ES-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.43	StillCrisis
IT-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.48	StillCrisis
IT-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.32	StillCrisis
PT-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.49	StillCrisis
PT-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.27	StillCrisis
IR-GR	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.45	StillCrisis
IR-GER	$\rho_S^* > \rho_T^*$	0.00	FTQ	$\rho_S^* < \rho_T^*$	0.48	StillCrisis

5. Conclusion

Our multivariate GARCH modeling of bond yields of major countries in the euro area over the period January 2008 - September 2013 brings several important and original results.

Concerning the conditional variance of returns, that is to say, the evaluation of risks perceived by investors, three patterns of evolution appear clearly. As for France and Germany, their bond yields are less volatile since the beginning of the sovereign debt crisis (period 2 in modeling) and the implementation of the OMT has accentuated this trend. For the Greek, Spanish, Italian and Portuguese bond markets, the conditional variances and perceived risks rise sharply during the crisis before falling with the implementation of the OMT. However, they don't return to the pre-crisis period levels. The Irish market has an intermediate evolution pattern with a peak of volatility during the crisis and then finish by a risk level lower than pre-crisis period.

The results also show that there is little evidence of volatility spillover between markets, with the exception of the link between the Greek market and the Irish market spotted during crisis.

The tests on conditional correlations of returns clearly show that the investors have followed a generalized logic of flight to quality since the beginning of the debt crisis. Therefore, we find a decrease in conditional correlations of bond yields. The implementation of the OMT and "Draghi put" had only the effect of blocking this process of decline of the correlations between markets. The French and German markets are the only two who return to their pre-crisis correlation level.

Our empirical results tend to support the argument that during the sovereign debt crisis the German and French bond markets have made an ideal investment haven for investors. The logic of the flight to quality and the protection against sovereign risk have contributed to a decline in interest rate the same as an increase of bond return.

Without doubt, the decrease in conditional variances of these returns also fueled more speculative strategies based on optimization of the return-risk pair in bond portfolios management.

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