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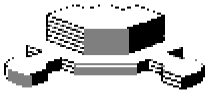

The 2007-? financial crisis: a euro area money market perspective

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Abstract

Motivated by the "shocking" evidence of non-stationary behavior of money market spreads during the crisis, we investigate the economic and statistical features of money market turbulence by means of a Fractionally Integrated Heteroskedastic Factor Vector Autoregressive model. This approach allows for an accurate modelling of the persistence properties of the data, and to decompose the EURIBOR-OIS spreads into three components bearing an economic interpretation. We find that the increasing trend in the spreads after August 2007 was broken and reversed in December 2008. This coincides with the timing of a large ECB policy rate cut which, together with other policy measures, paved the way for a gradual reversal in market sentiment, and reduction in credit and liquidity risks.

Key words: money market interest rates, credit/liquidity risk, fractionally integrated heteroskedastic factor vector autoregressive model.

JEL classification: C32, E43, E58, G15.

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[‡] The views expressed in this paper are of the exclusive responsibility of the authors and do not necessarily coincide with those of the ECB or of the Eurosystem.

1 Introduction

The evolution of the spreads between unsecured money market rates of various maturities and central banks' key policy rates has been subject to considerable debate and controversy in relation to the worldwide financial market turbulence that started in August 2007. Central to the recent controversy are the relative roles of *liquidity* and *counterparty (credit) risks* in explaining the size and dynamics of various money market spreads and the term structure of the spreads. Understanding what are the major driving forces behind the evolution of money market spreads has important implications for central bank policy, which is likely to be more effective in addressing liquidity problems (i.e. via Lender of Last Resort intervention) than for addressing solvency issues (which should be addressed by the fiscal authorities or through a banking resolution mechanism). In this debate there are two opposing views, particularly in the USA. On the one side of the debate, the financial crisis is seen as one of *banking solvency*, a view most prominent among academic economists, and vividly expressed by Taylor and Williams (2009); the authors in this camp strongly criticize central banks' liquidity interventions during the crisis for being either wrong or misguided and, at best, having had no effect. On the other side of the debate one finds, not surprisingly, mainly central bank economists, which tend to see the crisis as evolving in various stages, being the initial stage marked mainly by *liquidity problems,* subsequently "metastasized" into a solvency crisis; these authors tend to see central bank liquidity injections as rather appropriate and successful, at least during the first stages of the turbulence (see among others Christensen et al., 2009; McAndrews et al., 2008; Wu, 2008).

In this respect, it should be noted that a rigorous evaluation of the impact of central bank policies is plagued with difficult methodological problems. First and foremost, the counterfactual cannot be known; thus, whether and where central bank policies made a difference cannot be rigorously tested. Second, central bank interventions during the crisis amounted to replacing private financial intermediation that was sharply shrinking. A sharp and sudden shrinkage of the financial sector would have had a devastating impact on the "real" economy. Third, by accepting as collateral for refinancing securities that suddenly became illiquid (i.e. ABS), even without increasing the overall liquidity supply, central banks prevented a massive failure of financial institutions worldwide; even if those interventions did not have an immediate and visible impact on money market spreads, they may have prevented the emergence of even wider money market spreads and disorderly conditions in a broad range of financial markets.

Against this backdrop, we focus our attention on the spreads between

EURIBOR rates (unsecured) and Overnight Index Swaps (OIS; risk free) (OIS spreads) of various maturities; being sceptical about the feasibility of clear-cut separating credit and liquidity risks, i.e. liquidity and solvency banking problems in the context of the ongoing systemic financial crisis, due to the chain of derivatives contracts and the opacity of interbank linkages and over-the-counter transactions, it is assumed that spreads between unsecured and secured/risk free money market interest rates are best seen as *indicators of stress* in the money market, reflecting three inter-related factors: (1) credit/counterparty risk[1]; (2) liquidity funding/hoarding risk[2]; and (3) investor sentiment/risk appetite/confidence[3].

Most of the previous empirical work on the financial crisis has largely overlooked the complexity of the market environment and its implications for the statistical properties of the data. For example, the empirical analysis in Taylor and Williams (2009) relies on the strong correlation between money market spreads and CDS, assessing the effectiveness of central bank actions using dummy variable techniques within a no-arbitrage framework, to conclude that the former are a measure of credit risk only. This approach essentially treats liquidity risk as a residual, i.e. of an OLS-type regression of money market spreads on CDS spreads, and residuals may well capture other factors beyond liquidity risk; also, the linkage between money markets spreads and CDS may be unstable. Finally, during crisis periods prices do not necessarily fully reflect market clearing conditions (i.e. there are limits to arbitrage) and quantities are "clearing" the market (i.e. emergence of rationing); therefore, non-arbitrage models may fail to capture the underlying dynamics of risk factors during systemic crisis periods[4].

Differently, motivated by the "shocking" evidence of non-stationary behavior of money market spreads during the crisis, we investigate the economic and statistical features of money market turbulence by means of a novel Fractionally Integrated Heteroskedastic Factor Vector Autoregressive

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[1] Both EURIBOR and OIS rates incorporate expectations of the average overnight rate until maturity; these expectations cancel out when one computes EURIBOR-OIS spreads using rates of the same maturity, singling out, among other, counterparty risk which is priced in the EURIBOR rate but not in the OIS rate.

[2] A bank may not always be able to borrow in the overnight interbank market, i.e. credit lines are tightened following a rating downgrade, exposing to funding linquidity risk. A bank may also build up "excess reserves" (liquidity hoarding), in response to uncertainty about the valuation of its own assets and the availability of longer-term funding. See also Eisenschimdt and Tapking, 2009.

[3] As emphasized by Akerlof and Shiller (2009), *animal spirits* may have played an important role in the build up and unfolding of the crisis.

[4] That limited arbitrage is pervasive even under non-crisis market conditions is one of the corner stones of Behavioral Finance (see Shleifer 2000).

(FI-HFVAR) model. This approach allows for an accurate modelling of the persistence properties of the data, and decomposing the OIS spreads into three components bearing economic interpretation.

To preview the main findings of the paper, most of the non stationarity in the OIS spreads can be associated with the two waves of magnified stress in the interbank market, the first after 9 August 2007 and the second after 16 September 2008, which led to permanent changes in the levels, variances and persistence of the spreads. These capture the long lasting (permanent) effects of the financial market crisis on credit risk, liquidity risk and confidence. The increasing trend in the OIS spreads was broken and reversed after the ECB cut its key policy rate by 75 bps, a move that took markets by surprise. This, together with other policy measures, like the policy of full allotment at a fixed rate in all refinancing operations, including longer-term maturities and TAF-related US dollar credit provided by the ECB, may have paved the way for a gradual reversal in market sentiment, and reduction in credit and liquidity risk.

The remainder of the paper is structured as follows. Section 2 presents the econometric methodology. Section 3 reports the econometric results on persistence and Section 4 on copersistence and the estimation of the FI-HVAR. Section 5 concludes.

2 Econometric methodology

The dynamics of the OIS interest rate spreads (x_t) are modelled according to the following fractionally integrated heteroskedastic factor vector autoregressive (FI-HFVAR) model

$$\begin{aligned} x_t &= \Lambda_\mu \mu_t + \Lambda_f f_t + C(L)(x_{t-1} - \Lambda_\mu \mu_{t-1} - \Lambda_f f_{t-1}) + v_t \qquad (1) \\ v_t &\sim iid(0, \Sigma_v) \\ D(L) f_t &= \eta_t = \sqrt{h_t}' \psi_t, \qquad (2) \\ \psi_t &\sim iid(0, \Sigma_\psi) \\ M(L)(h_t - w_t) &= [M(L) - N(L)]\eta_t^2 \qquad (3) \end{aligned}$$

where x_t is a n-variate vector of real valued integrated processes subject to structural breaks, $t = 1, ..., T$, L is the lag operator, f_t is a r-variate vector of heteroskedastic integrated, of order d in mean, and b in variance, common factors, with $0 \leq d_i \leq 1$, $0 \leq b_i \leq 1$, $i = 1, ..., r$, μ_t is an m-variate vector of common break processes, v_t is a n-variate vector of zero mean idiosyncratic i.i.d. shocks, with contemporaneous covariance matrix Σ_v, assumed to be coherent with the condition of weak cross-sectional correlation of the idiosyncratic components (Assumption E) stated in Bai (2003, p.143), ψ_t is a r-variate vector of common zero mean i.i.d. shocks, with covariance matrix $\Sigma_\psi = I_r$, $E[\psi_{it} v_{js}] = 0$ all i, j, t, s, Λ_f and Λ_μ are $n \times r$ and $n \times m$, respectively, matrices of loadings, $C(L)$ is a finite order stationary matrix of polynomials in the lag operator, i.e. $C(L) \equiv C_1 L + C_2 L^2 + ... + C_s L^s$, C_j $j = 1, .., s$ is a square matrix of coefficients of order n,

$$D(L) = diag\left\{(1-L)^{d_1}, (1-L)^{d_2}, ..., (1-L)^{d_r}\right\}$$

$$M(L) = diag\left\{(1-\beta_1 L), (1-\beta_2 L), ..., (1-\beta_r L)\right\}$$

and

$$N(L) = diag\left\{\phi_1 L(1-L)^{b_1}, \phi_2 L(1-L)^{b_2}, ..., \phi_r L(1-L)^{b_r}\right\}$$

are diagonal stationary polynomial matrices in the lag operator of order r. Hence, h_t is the time dependent r-variate conditional variance vector process, defined as $h_t = Var(f_t|\Omega_{t-1})$, following the $A\text{-}FIGARCH(1, d, 1)$ process of Baillie and Morana (2009), where w_t is the long-term conditional variance process or the break in variance process. Non negativity constraints, involving the β_i, ϕ_i, and b_i parameters, for well defined conditional variance processes are discussed in Baillie and Morana (2009) and imposed in estimation following the exponential specification of Engle and Rangel (2008). The long memory factors f_t, are also assumed to be conditionally orthogonal, i.e. $q_{f,t} = Cov(f_{i,t}, f_{j,s}|\Omega_{t-1}) = 0$ all i, j, t, s.

2.1 Estimation and properties

Estimation of the FI-HVAR model can be achieved following a multi-step procedure, involving:

i) persistence analysis, to determine whether the series contains either long memory or structural breaks or both;

ii) copersistence analysis, using principal components analysis (PCA), to determine whether the long memory and or structural break components are common across series;

iii) iterative estimation, conditional to the estimated fractional differencing parameter in *i*) and the initial estimate of the unobserved common features in *ii*), of the parameters (OLS) and unobserved features (PCA) in the model;

iv) the above procedure is simulated, in order to obtain median estimates of the parameters of interest, and confidence intervals robust to model misspecification; identification of the common and idiosyncratic shocks is performed by means of a Choleski based approach, and impulse response functions and forecast error decomposition computed.

v) the conditional variance of the common long memory factors and series can be estimated by implementing an A-FIGARCH version of the O-GARCH model of Alexander (2002), using median factor estimated residuals.

Consistency and efficiency properties of the above estimation procedure, as well as full details on the actual implementation of the procedure are discussed in Morana (2010). Monte Carlo results, provided in Morana (2010), yield full support to the proposed methodology, being accurate under several scenarios, featuring either short or long memory, both covariance stationary and non stationary, observational noise, relatively small cross-sectional dimensions and small time series samples.

3 Statistical features of OIS spreads in crisis times

The sample covered in the econometric analysis runs from 20 June 2005 until 7 April 2009, for a total of 992 working days. The data set is composed of fifteen OIS interest rate spreads, from the 1-week maturity (w_t^{1w}) to the 1-year maturity (w_t^{12m}). The data is of daily frequency and its source is REUTERS.

3.1 Persistence analysis

Persistence in spreads may be due to either long memory or structural breaks, or both; a modelling framework allowing to account for both features, and to distinguish among them, should then be employed. The Dolado et al. (2004, DGM) structural break test, modified to account for a general and unknown structural break process (Morana, 2009), has therefore been employed in order to assess the source of persistence in the investigated series. Moreover, also the Bai and Perron (1998, BP) test has been employed in order to gauge evidence on the number and location of break points. Finally, the Moulines and Soulier (1999, BBLP) broad band log periodogram estimator has been employed to assess the degree of fractional integration of the actual and break-free OIS spreads.

3.1.1 Deterministic persistence

As shown in Table 1, for the conditional mean equation, the evidence points to two break points with similar location across maturities, the former occuring between 9 August and 16 August 2007, and the latter on 16 September 2008, which can be related to the starting days of the two *stress waves* in the money market. The beginning of the first wave is on 9 August 2007, i.e. the day the French bank BNP Paribas revealed its inability to value structured products for three of its investment funds. The crisis triggered several interventions by the European Central Bank and the US Federal Reserve, injecting extra overnight funds.[5] The interbank market stress was indeed sizable, with the average spread moving from a range of 3b.p. (1-week) to 7b.p. (1-year), to a range of 15b.p. to 74b.p. until 15 September 2008.[6] After 16 September 2008, the day after the bankruptcy of Lehman Brothers, which can be taken as the starting day for the second wave of money market stress[7], the OIS spreads climbed rapidly, to reach maximum values in the range of 100b.p. to 233b.p. between October 8 and October 13, depending on the maturity (sample average values after the second wave of stress are in the range 28b.p. to 155b.p.). In the face of major difficulties in the banking sector in the US and Europe, policy rate cuts, various forms of liquidity provision and non-standard monetary policy measures after short-term market rates reached zero or near-zero levels. These measures were taken by central banks with the aim of defreezing the interbank and credit markets, and easing the banking sector from the burden of non-performing assets, as well as to facilitate its recapitalization, supported by the intervention of the governments.[8]

Moreover, also 5 December 2008 could be selected as an additional break point, which coincides with the 75b.p. cut announced on 4 December 2008 by the ECB and implemented on 10 December 2008. In addition to a sizeable contraction in the OIS spreads, in the range -11% to -31% (-16% on average), also a reversal in the OIS spreads trend can be observed: since 5 December 2008 OIS spreads have steadily decreased, converging towards first stress wave levels; yet, by the end of our sample, i.e. 7 April 2009, only the one-, two- and three-week rates had actually achieved pre-Lehman Brothers bankruptcy levels; for the one-year rate the distance was still close to 20b.p.. This finding is fully consistent with the evidence that the financial crisis spilled over to the real economy since the fourth quarter of 2008.

As the minimum regime length is fixed at $0.15T$, the significance of the suggested additional break point could not be tested by means of the BP

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[5] A Federal funds rate cut of 50 b.p. was implemented on 17 August 2007. Additional Fed funds rate cuts were implemented on 18 September 2007 (50 b.p.) and 31 October 2007 (25 b.p.).

[6] See Brunnermaier (2009) for insights on the US sub-prime credit crisis.

[7] It is September 16 2008, rather than September 15 2008, the starting day of the second wave of panic for Europe, due to lagged markets opening effects.

[8] See Reis (2009) for insights on the policies implemented by the Fed during the crisis, and Section 4 concerning ECB policies.

test. Implementation within the DGM testing framework, however, suggests that the additional selected break point, as well as the changing slope structure, is appropriate for the data investigated (see the next Section for details). Moreover, as the changes in the level of the variables occur consecutively in the range of few days, rather than in just a single day, the break process specification should allow for a step function, with break structure as discussed above, yet with smooth transition across regimes. The proposed dummy model with smooth cubic spline transition (DCSM) is implemented by means of a two-step procedure, i.e. the application of OLS estimation first, and then spline smoothing in the neighborhood of the break points in the estimated dummy break process (see Silverman (1985) for details on estimation of spline functions).

Also the volatility component has been assessed for structural breaks by means of the BP test, using the absolute first difference of the spreads as volatility proxy. While the increase in long-term volatility triggered by the unfolding of the crisis and the spreading of the first stress wave is undisputable (from a range of 1.0b.p. to 1.5b.p., across maturities, over the preturmoil period, to a range of 9b.p. to 19b.p. over the first stress wave period), less clear-cut is whether a further increase in long-term volatility occurred following the spreading of the second stress wave (to a range of 20b.p. to 45b.p. over the second stress wave period). As shown in Table 1, the location of the break points for the conditional variance equation is similar to the findings for the conditional mean equation, with breaks occurring around 9 August 2007 and 16 September 2008. Yet, the selection of the latter break point is not robust to the selection method employed: consistent with the findings for the spreads levels, a progressive reduction in volatility towards first stress wave's overall levels can be noted at the end of the investigated sample.[9] Hence, after some experimentation, a single break point, i.e. 9 August 2007, has been retained for the conditional variance equation.

Hence, the following break process specifications have been employed:

$$b_t = (\alpha_0 + \alpha_1 D_{1,t} + \alpha_2 D_{2,t} + \alpha_3 D_{3,t} + \alpha_4 D_{4,t}) \sqcup f_p(t),$$

for the conditional mean equation, and

$$b_t = (\alpha_0 + \alpha_1 D_{1,t}) \sqcup f_p(t),$$

for the conditional variance equation,

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[9] The modified BIC criterion (LWZ) points to a single break point occurring on 9 August 2007 for all the series, apart from maturities between the two-month and seven-month horizon. The results are avaialble upon request from the authors.

where $t = 1, ..., T$, $T = 992$, D_1 is a (first stress wave) step dummy variable with unity value over the period 9 August 2007 to 7 April 2009 inclusive, D_2 is a (second stress wave) step dummy variable with unity value over the period 16 September 2008 to 7 April 2009 inclusive, D_3 is a (second stress wave) broken linear trend variable, with non-zero values over the period 16 September 2008 to 4 December 2008 inclusive, D_4 is a (stress resolution) broken linear trend variable, with non-zero values over the period 5 December 2008 to 7 April 2009 inclusive, and $f_p(t)$ accounts for the smooth cubic spline transition across regimes.

3.1.2 Stochastic persistence

As shown in Table 1, according to the BBLP estimator, strong (non stationary) long memory, not statistically different across maturities, can be found in the actual OIS spreads, with an average estimated fractional differencing parameter of about 0.94. Due to the break in the unconditional mean and variance of the OIS spreads, the fractional differencing parameter has also been estimated for the break-free series, standardized according to the selected regimes for their unconditional variance. Results show that sizable long memory can also be found in the standardized break-free series, in the range 0.24 to 0.64 (0.40 on average). A statistically significant hump-shaped profile can be noted in the cross-section of persistence, the latter increasing with maturity up to the three-week horizon and decreasing thereafter. Yet, similar persistence can be found for consecutive maturities.

The finding of significant long memory in both the actual and standardized break-free specifications points to non spurious structural change in the OIS spreads, as, otherwise, evidence of overdifferencing, i.e. a negative estimate for the fractional differencing parameter, would be expected (Granger and Hyung, 2004). The DGM test supports the latter conclusion, pointing to significant break processes, of the DCSM type, for all the (actual) OIS spreads, as the null of pure long memory process is rejected in all cases, at the 5% significance level.[10]

Evidence of significant instability can also be detected in the estimated persistence parameter, when computed separately for the pre-crisis and crisis periods. The null of temporal stability is in fact strongly rejected both using a Bonferroni bounds joint test and a maturity by maturity pairwise comparison (see Table 1).

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[10] Critical values for the test have been computed by simulation, also allowing for unconditional heteroskedasticity under the null. Details are available upon request from the authors.

4 The FI-HFVAR model

Given the evidence of both long memory and structural breaks in the level of the OIS spreads, consistent with the multi-step procedure to be implemented for estimation of the FI-HVAR model, the presence of commonalities in the break process and (break-free) long memory components has been investigated. Commonalities for each component, across the term structure, should be expected, since, as shown in Table 2, for the actual OIS interest rate spreads, PCA singles out a single factor accounting for about 99% of total variance, and over 95% of the variance for each OIS spreads, from the 2-week maturity onwards.

4.1 Cobreaking and common long memory factor analysis

4.1.1 Level factor of OIS spreads

As shown in Table 2, the strong commonality detected for the actual variables, can also be noted once the break process component is isolated from the long memory component. In fact, PCA singles out a single common break process accounting for over 99% of total variance for the break process series, the latter also accounting for about or over 90% of the variability for each break series (Figure 1, top plot). The latter component, being related to the two waves of increasing bank stress, captures the *level* of OIS spreads in the crisis period, reflecting, among other factors, *confidence (risk appetite).*

Of particular interest is the break point following the announcement of the larger than expected rate cut by the ECB on 5 December 2008, when a declining trend in the levels of the OIS spreads started. The latter highlights the importance of the rate cuts by the ECB (as well as by other central banks) in contributing to improving the level of confidence in the money market. Of course, rate cuts also contributed directly to improving the credit and liquidity prospects for banks.[11] As shown in Figure 2, the declining trend coincides with the timing of the rate cuts by the ECB in a sequence of steps (five in the sample period; middle plot), reinforcing the full allotment policy[12], started in October 2008, which generated excess liquidity in the

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[11] In a risk-neutral valuation framework the probability of default and the recovery rate are the main determinants of the credit spread. A decrease in the level of the short-term rate may lead to a decrease in the probability of default.

[12] The latter policy consisted in allotting in full at a fixed rate all bids submitted by banks at all open market operations conducted by the ECB for all maturities (one-week, one-, three- and six-month maturities) in the sample period.

money market (middle plot). As illustrated in Figure 2 (after observation 863, middle plot), the liquidity surplus led to systematic and large recourse to the deposit facility of the Eurosystem[13], so that the ECB was simultaneously providing longer-term credit to the banking system and taking short-term deposits from it, in short, playing a financial intermediary role.

Finally, note that towards the end of the sample period (after observation 900), while the common spreads level was on a declining trend a measure of banks' credit risk (iTraxx Euro Financials) kept on rising, thereby casting some doubts about any stable relationship between OIS spreads and CDS-based measures of credit risk (bottom plot); indeed this evidence gives strong support to the hypothesis that beyond credit risk considerations, liquidity risk and/or confidence factors were also relevant in explaining the evolution of the OIS spreads, also casting doubts on the robustness of the findings in Taylor and Williams (2009).

4.1.2 Curvature and slope factors of OIS spreads

Turning to the long memory components, PCA singles out two common long memory factors (Figure 1, central plots), jointly accounting for over 80% of total variance (65% and 18%, respectively), the former affecting all the maturities, and the latter being closely related to the shortest maturities; as higher order principal components mainly capture idiosyncratic features, also the selection of the common long memory factors is then clear-cut. As shown in Table 2, in terms of their persistence properties, both stochastic factors show the long memory feature, with estimated fractional differencing parameters consistent with the findings of persistence analysis: the estimated parameters are 0.32 and 0.52, for the first and second principal components, respectively, and 0.42 on average. Subsample (pre-crisis and crisis) estimation and testing, point to a significant increase in persistence following the unfolding of the crisis (doubling for the first factor and a three fold increase for the second factor), moving from stationary long memory (the fractional differencing parameters are 0.24 and 0.44 for the first and second factor, respectively) for the pre-crisis sample to non stationary long memory (the fractional differencing parameter is 0.87 for both cases) for the crisis sample. The discontinuity in persistence can be easily appreciated in Figure 1, show-

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[13] *Excess liquidity* is measured by the daily net recourse to the deposit facility of the Eurosystem (NSF = recourse to marginal lending facility - recourse to the deposit facility). The deposit facility has an overnight maturity and its remuneration is below market rates thereby setting the floor for the level of the overnight interest rate. The marginal lending facility has also an overnight maturity and has a penalty rate thereby setting the ceiling for the overnight interest rate.

ing a sizable increase in persistence following 9 August 2007 (observation 559), as the (standardized) common long memory factors appear to be much smoother than before.

Long memory and structural change also affect the volatility of the common long memory factors; while long memory in variance is not strong, as the estimated persistence parameters are about 0.10 and 0.23, for the first and second common long memory factors, respectively, the change in the level and range of variation of volatility, after the unfolding of the crisis, is remarkable (a four fold increase) (Figure 1, bottom plots). For both factors the increase in volatility was particularly strong at the outset of the crisis in August 2007 and following Lehman bankruptcy in mid September 2008; reversion to pre-Lehman volatility levels is already evident starting from mid December 2008, and possibly associated with the progression of interest rate cuts, reinforcing the excess liquidity creation achieved by the full allotment policy.

Curvature factor of OIS spreads As shown in Table 3, although the first common long memory factor accounts for dynamics common to all the OIS spreads, it is dominating for maturities above one-month and, in particular, for maturities between three and six-months. This feature is reminiscent of a *curvature factor* capturing the medium-term evolution in the OIS spreads during the crisis period. As illustrated in Figure 3 (top plot) the peaks in this component coincide with moments when the major central banks announced coordinated actions, in particular announcements on US dollar operations which, in the context of the US Fed Term Auction Facility (TAF), allowed banks outside the US market to get US dollar funding directly (against collateral), namely from European central banks (i.e. ECB, Bank of England and Swiss National Bank).[14] Note that after each of the three major announcements highlighted by vertical bars in Figure 3 (top plot) this component of OIS spreads either declined sizably or stabilized, suggesting some effectiveness of the measures in alleviating money market tensions.[15] In fact, the

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[14] The US dollars were provided by the US Fed to the European central banks via bilateral swap lines.

[15] The first two bars (observations 648 and 650, December 12 and 14 2007) correspond to: 1) communication on joint action ECB and US Fed Res on dollar funding via USD TAF (2 auctions were announced with 28 and 35 day maturities to be conducted on 17/Dec/07 and 20/Dec/07 up to USD 20 billion); 2) joint announcement of measures to address money market tensions by Bank of Canada, BoE, ECB, US Fed, and SNB). The third bar (observation 712, March13 2008) corresponds to joint announcement by ECB, BoEngland, US Fed, BoCan, SwissNB on USD operations. The fourth bar (observation 863, August 10 2008) corresponds to the day of the announcement of full allotment in (TAF-related) ECB US dollar credit operations, matched by a correspondent swap line of unlimited amount

cross correlation analysis suggests that the announcements on coordinated actions are positively correlated to developments in the first common long memory factor (Figure 3; middle panel, left hand side plot).

Of interest is also the cross-correlation with the share of longer-term refinancing operations in total refinancing volume (LTRO/Total) (Figure 3; lower panel, left hand side plot), which is negative and significant, suggesting that the ECB policy of increasing the share of longer-term operations in the total outstanding refinancing volume (one-month, three-month and six-month maturities), contributed to decreasing the OIS spreads, in particular, between the three and six months maturities (indeed a kind of *curvature* effect).

Slope factor of OIS spreads The second common long memory factor mainly explains dynamics at the shortest end of the OIS spreads term structure. This feature is reminiscent of a *slope factor* capturing the medium-term evolution in the OIS spreads during the crisis period. This *slope* factor might capture a “pure” liquidity risk component. Interestingly as illustrated in Figure 4 (top plot) there seems to be a close correlation during the crisis between this component and large volume fine-tuning operations (FTOs) conducted by the ECB. Note that negative fine-tuning operations refer to liquidity absorbing operations and positive FTOs to liquidity providing ones. Thus, the positive contemporaneous correlation between the second long-memory component and FTOs indeed suggests that the former captures movements in the OIS spreads associated with shorter-term liquidity imbalances, which are being "corrected" by the ECB (Figure 4; middle panel, right hand side plot).

Also the cross-correlation with the share of longer-term refinancing operations in total refinancing volume (LTRO/Total) (Figure 4; lower panel, left hand side plot), statistically significant and positive, is of some interest: the ECB policy of increasing the share of longer-term operations in the total outstanding refinancing volume, whilst contributing to decreasing term spreads (curvature effect documented above), led to an increase in the OIS spreads at the very short-end of the money market curve, in what looks like a substitution (slope) effect.

4.2 Further results for the FI-HFVAR model

In the light of PCA results, pointing to a single common break process and two common long memory factors, the dimension of the FI-HFVAR model is set to seventeen equations, corresponding to the fifteen money market

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from the US Fed to the ECB.

OIS spreads plus the two common long memory factors. In the light of the detected instability in persistence, the model has been estimated by allowing the fractional differencing parameter to take different values for the pre-crisis and crisis period. Moreover, median estimates of the parameters and confidence intervals have been computed by selecting the order of the short memory autoregressive polynomial ($C(L)$) by information criteria, yielding a first order optimal model, and then setting to ten the order of the long memory autoregressive polynomial ($\Phi(L)$) and to 1000 the number of Monte Carlo replications. Also, consistent with the finding of structural instability in the unconditional variance for the OIS spreads, the unconditional variance-covariance matrix employed for the policy analysis has been allowed to change according to the sub period (pre-crisis/crisis) investigated.

4.3 Forecast error variance decomposition and impulse response analysis

The results of the forecast error variance decomposition are clear-cut, and reported in Table 3; two horizons, i.e. 1-day and 20-day, have been considered in the analysis.

Firstly, for the pre-crisis period, independently of the maturity, the joint contribution of the common factor shocks to fluctuations is similar for both horizons, i.e. 57% to 92% (1-day) and 48% to 99% (20-day); 90% on average for both cases; differently, for the crisis period the common shocks are always dominating at long horizons (85% to 100%; 98% on average), yet dominating at short horizons only from the 4-month maturity onwards (14% to 42% from 1-week to 3-month, 29% on average; 77% to 99% from 4-month to 1-year, 96% on average). Hence, as a consequence of the crisis, short-term fluctuations have become more idiosyncratic, particularly at the very short end of the term structure (particularly large is the contribution of the own idiosyncratic shock for the 1-week maturity, i.e. about 90%, and still sizable within the three-month maturity, i.e. 70% on average).

Secondly, for the pre-crisis period, the *curvature* factor never accounts for more than 30% of fluctuations within the 3-month maturity, and for no less than 40% for longer maturities. Interestingly, a hump shaped profile can be detected, with the *curvature* factor being relatively more important for medium-term maturities (3- to 9-month) than at the short or long end of the term structure. A similar evidence can also be found for the crisis period. Yet, for the latter period, the *curvature* factor yields a more uniform contribution across maturities. For instance, while its contribution, at the 1-day horizon, is never above 20% within the 3-month maturity, at the 20-day horizon its contribution is never below 30%.

Thirdly, the second factor, i.e. the *slope* factor, is dominating at the very short and long end of the term structure, albeit important differences can be detected for the pre-crisis and crisis periods. Over the pre-crisis period, the *slope* factor never accounts for less than 50% of total fluctuations for maturities within the 3-month and beyond the 9-month horizon, at both the 1-day and 20-day horizon. On the other hand, over the crisis period, due to the increased importance of idiosyncratic fluctuations, the proportion of accounted variance is lower, i.e. never larger than 30% at the 1-day horizon (within the 3-month maturity), and just over 50% at the 20-day horizon (yet only within the 1-month maturity); the contribution of the *slope* factor is then sizable again for maturities at the long end of the term structure, i.e. over 25% from the 9-month maturity onwards at the 1-day horizon.

Concerning the impulse response analysis, as shown in Figure 5, major differences can be noted between the pre-crisis and crisis periods, both in terms of magnitude and persistence of common factor shocks, as well as of response profiles. Important differences can also be noted, within each period, across maturities, as it is portrayed by the comparison between the results for the 1-week and 1-year maturities.

Concerning *curvature* shocks (top four plots), both the persistence and magnitude of the impact increase, in general, with the maturity of the OIS spreads. For instance, over the pre-crisis period, the *curvature* shock has a five fold larger impact on the 1-year OIS spread than on the 1-week OIS spread; moreover, while the rate of decay of the shock is much faster for the 1-week rate, with a zero point impact attained already after one day, for the 1-year rate about twenty days are required for full point dissipation; a similar gap in the magnitude of the impact across maturities can also be detected for the crisis period; yet, as shown by the response profiles, shock persistence is much higher over the crisis period (hump-shaped profile) than over the pre-crisis period (monotonic decay), with dissipation occurring well beyond twenty days.

Concerning *slope* shocks (bottom four plots), a similar impact, in absolute terms, can be found across maturities. Yet, beyond the 3-month maturity, different from shorter maturities, a positive *slope* factor shock exercises a negative impact on the OIS spreads. Moreover, different from the *curvature* factor shock, slightly stronger persistence can also be detected for shorter maturities than for longer maturities for both periods, while, similarly to the *curvature* factor shock, the rate of decay of shocks is much faster over the pre-crisis (monotonic decay) than the crisis period (hump-shaped profile).

Differences between periods can also be found concerning the effects of idiosyncratic shocks (not reported). While the response profile is similar, pointing to a monotonic decay in both cases, over the crisis period a five fold larger impact can be detected. Moreover, stronger persistence can be detected for shorter maturities than for longer maturities, full dissipation requiring about ten and five days, respectively.

5 Conclusions

In this paper the consequences of the recent financial turmoil for the euro area money market have been assessed by investigating the persistence properties of the mean and variance of the OIS spreads in the framework of a FI-HVAR model. It is found that most of the non stationarity in the OIS spreads can be associated with the two waves of magnified stress in the interbank market, the first after 9 August 2007 and the second after 16 September 2008, which led to permanent changes in the levels, variances and persistence of the spreads, and therefore to long lasting (permanent) effects of the financial market crisis on confidence, and credit and liquidity risks. Deviations of the OIS spreads from their long-term (time-varying) values tend to be corrected slowly due to their long memory feature. Also, the increasing trend in the OIS spreads was broken and reversed after the ECB cut its key policy rate by 75 bps on December 2008; this, together with other policy measures, like the policy of full allotment at a fixed rate in all refinancing operations, may have paved the way for a gradual reversal in market sentiment, and reduction in credit and liquidity risks. An important question that is left open is the permanent consequences of the crisis on the money market which may not necessarily return to pre-crisis features. While a reduction in persistence to stationary long memory could be expected, i.e. mean reverting spreads, as well as a sizable contraction in volatility, the level of OIS spreads might not come back to pre-crisis values. Surely, a peculiar feature of the pre-crisis euro area money market was the virtual absence of OIS spreads. As a consequence of the crisis, sizable OIS spreads became a feature of the money market. Whether they will remain so also in the future is an open question.

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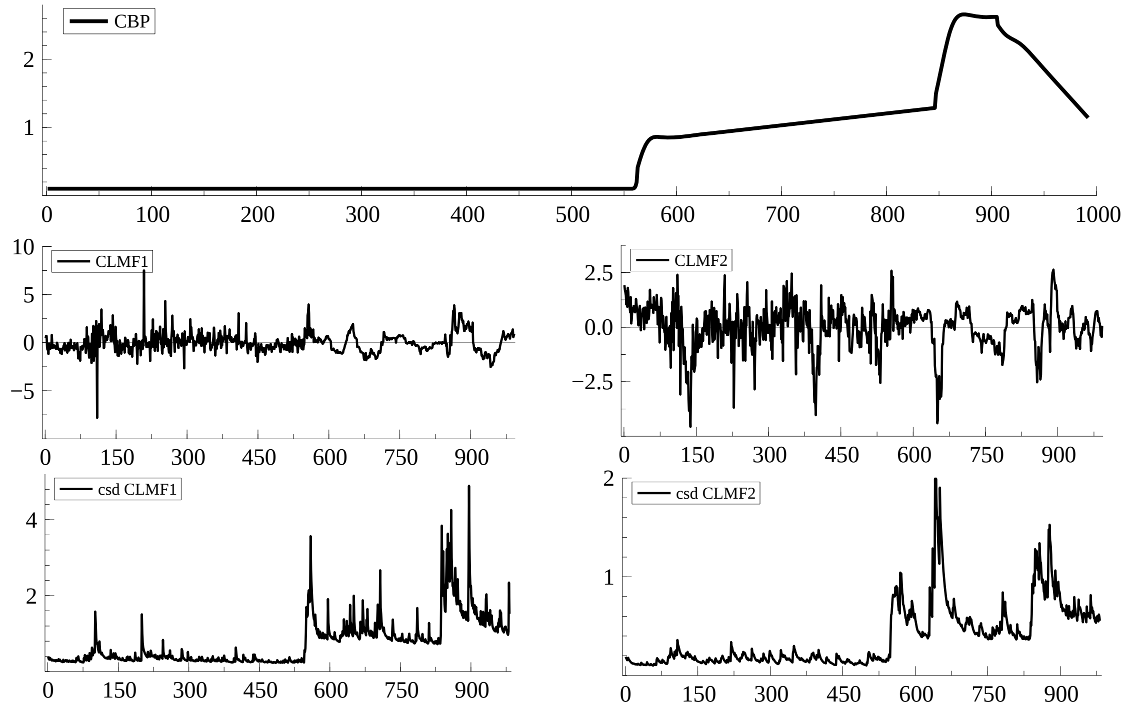

Figure 1: level factor (CBP), (standardized) curvature (CLMF1) and slope (CLMF2) factors and their volatility (csd CLMF1, csd CLMF2).

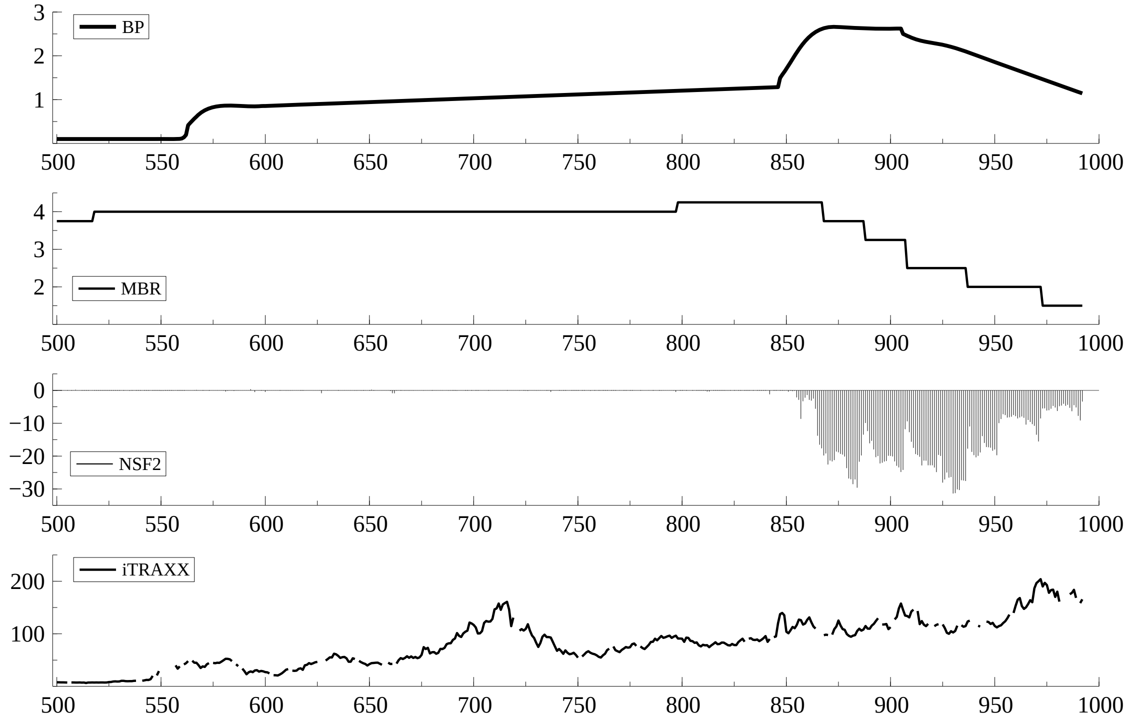

Figure 2: level factor (CBP), minimum bid rate (MBR), net standing facilities (NSF) and iTRAXX Financials index.

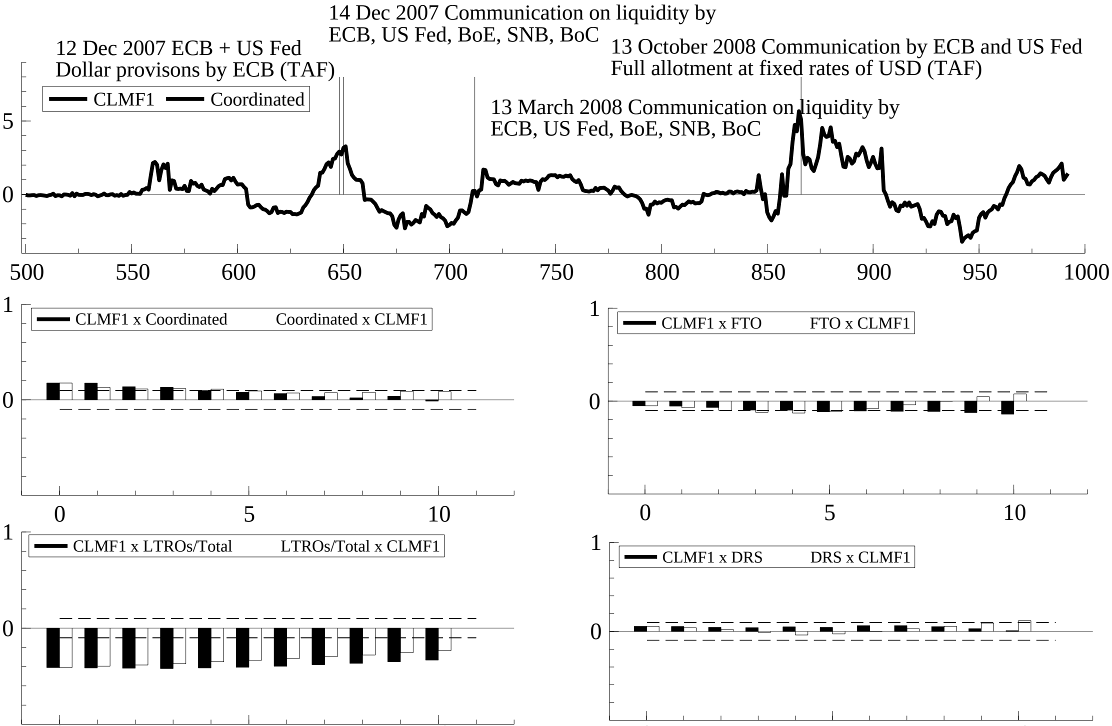

Figure 3: (standardized) curvature factor (CLMF1) and main coordinated central bank actions (top plot). Cross correlation functions of CLMF1 with main coordinated central bank actions, fine tuning operations (FTO), long term operations/total operation (LTROs/Total), and frontloading of the fulfilment of the reserve requirements (DRS) (other plots).

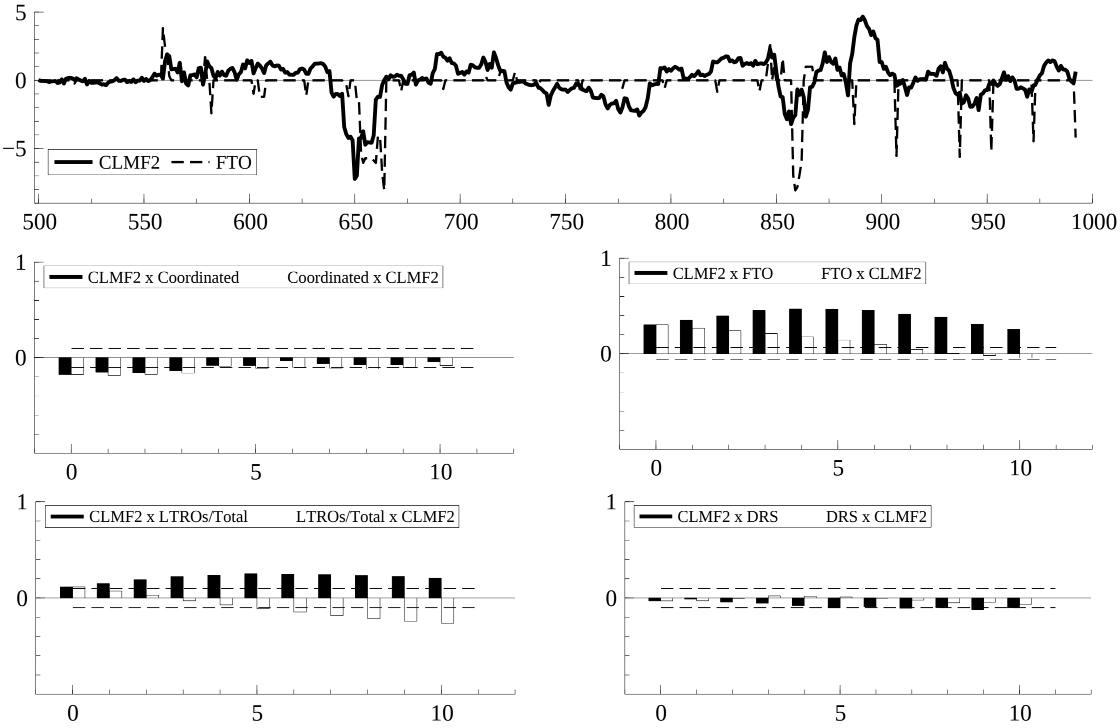

Figure 4: (standardized) slope factor (CLMF2) and fine tuning operations (FTO) (top plot). Cross correlation functions of CLMF2 with main coordinated central bank actions, fine tuning operations (FTO), long term operations/total operation (LTROs/Total), and frontloading of the fulfilment of the reserve requirements (DRS) (other plots).

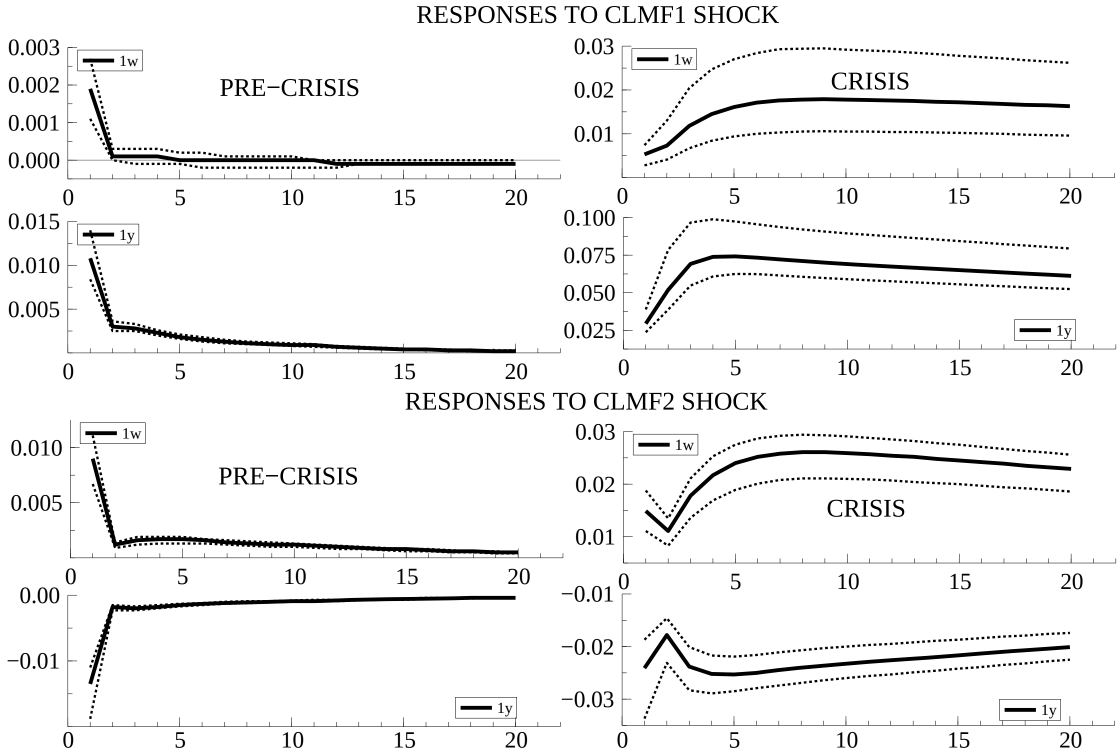

Figure 5: impulse responses, with 95% confidence interval, to a unitary curvature factor (CLMF1) shock and slope factor (CLMF2) shock, for the pre-crisis (left hand side plots) and crisis (right hand side plots) periods, for the 1-week (1w) and 1-year (1y) maturities.

Table 1: EO spreads, persistence analysis: structural breaks tests and long memory analysis

Structural break tests						***Long memory analysis***		
	Bai-Perron				***DGM***	***MS broad band log periodogram***		
	mean		***volatility***		$s = 0$	***mean***		
	break	***BIC***	***break***	***BIC***	***DCSM***	***actual***	$\boldsymbol{bf_{DCSM}}$	$\boldsymbol{eq_{DCSM}}$
w^{1w}	558, 844	-4.758	557, 844	-6.883	0.005	0.857 (0.041)	0.455 (0.041)	1E-05
w^{2w}	560, 844	-4.580	558, 844	-6.643	0.005	0.899 (0.041)	0.600 (0.041)	0.012
w^{3w}	560, 844	-4.311	557, 844	-6.887	0.005	0.980 (0.041)	0.644 (0.041)	0.003
w^{1m}	561, 844	-3.793	558, 844	-7.183	0.010	1.029 (0.041)	0.567 (0.041)	2E-04
w^{2m}	561, 844	-3.697	553, 844	-7.797	0.025	1.035 (0.041)	0.472 (0.041)	1E-10
w^{3m}	562, 844	-3.699	553, 844	-8.015	0.050	0.996 (0.041)	0.459 (0.041)	1E-10
w^{4m}	562, 844	-3.683	554, 844	-7.863	0.030	0.962 (0.041)	0.386 (0.041)	1E-10
w^{5m}	563, 844	-3.626	554, 844	-7.744	0.010	0.939 (0.041)	0.370 (0.041)	1E-10
w^{6m}	563, 844	-3.584	554, 844	-7.715	0.005	0.934 (0.041)	0.344 (0.041)	1E-10
w^{7m}	563, 844	-3.522	558, 844	-7.603	0.005	0.934 (0.041)	0.327 (0.041)	1E-10
w^{8m}	563, 844	-3.453	558, 844	-7.506	0.005	0.919 (0.041)	0.307 (0.041)	1E-10
w^{9m}	563, 844	-3.383	558, 844	-7.420	0.005	0.918 (0.041)	0.275 (0.041)	1E-10
w^{10m}	563, 844	-3.319	554, 844	-7.343	0.005	0.912 (0.041)	0.260 (0.041)	1E-10
w^{11m}	563, 844	-3.257	548, 844	-7.296	0.005	0.904 (0.041)	0.244 (0.041)	1E-10
w^{1y}	563, 844	-3.196	548, 844	-7.265	0.005	0.890 (0.041)	0.277 (0.041)	3E-10
mean						**0.941 (0.041)**	**0.399 (0.041)**	**0.001**
b test						**0.002**	**1E-10**	
$\boldsymbol{b_{sub}}$ ***test***								**1E-10**

In the Table the results of the Bai-Perron (BP, columns 1 to 4) and Dolado-Gonzalo-Mayoral structural break tests are reported. The BP tests have been carried out on both the actual series x_t and on a volatility proxy obtained from $| \Delta x_t |$. In the table, the estimated location of the selected break points and the associated BIC value are reported. The DGM test has been carried out assuming a time-varying unconditional variance. The latter takes two values according to the estimated values for the period 20/06/05 to 8/08/07 and 9/08/07 to 7/04/09. In the table the p-value of the DGM test has bee reported for the dummy-spline model (DCSM), for the zero-lag case ($s = 0$). The estimated fractional differencing parameters, with standard errors in brackets, for the actual and DCSM break-free (*bf*) series, obtained using the Moulines and Soulier (1999) broad band log periodogram estimator, are also reported (columns 6-9). "*b test*" is the p-value of the test of equality of the fractional differencing parameter across maturities, while "b_{sub} *test*" is the p-value of the test of equality of the fractional differencing parameter across maturities and subsamples. Finally, eq_{DCSM}, for each maturity, is the p-value of the test for the equality of the fractional differencing parameter across subsamples. The results are reported for the various EO spreads maturities available, i.e. from 1-week (w^{1w}) to one-year (w^{1y}).

Table 2: EO spreads, copersistence (principal components) analysis

Panel A: Principal components analysis

	actual	***bp_{DCSM}***	***bf_{DCSM}***	
	f_1	***f_1***	***f_1***	***f_2***
tot	**0.997**	**0.997**	**0.651**	**0.175**
w^{1w}	0.907	0.897	0.086	0.410
w^{2w}	0.975	0.959	0.152	0.583
w^{3w}	0.983	0.969	0.227	0.553
w^{1m}	0.968	0.953	0.341	0.437
w^{2m}	0.982	0.990	0.559	0.112
w^{3m}	0.988	0.992	0.717	0.031
w^{4m}	0.995	0.997	0.826	0.005
w^{5m}	0.998	0.999	0.878	0.002
w^{6m}	0.999	0.999	0.935	0.017
w^{7m}	0.999	0.999	0.924	0.044
w^{8m}	0.999	0.999	0.896	0.069
w^{9m}	0.999	0.999	0.863	0.080
w^{10m}	0.998	0.998	0.816	0.083
w^{11}	0.996	0.997	0.785	0.094
w^{1y}	0.994	0.996	0.764	0.102

Panel B: Long memory analysis of common stochastic factors

	***d* (se)**	***eq***	***d_{pc}* (se)**	***d_c* (se)**
$f_{1,DCSM}$	0.320 (0.041)	1E-10	0.243 (0.054)	0.886 (0.062)
$f_{2,DCSM}$	0.516 (0.041)	1E-07	0.441 (0.054)	0.874 (0.062)
mean	**0.418 (0.041)**	0.070	**0.342 (0.054)**	**0.880 (0.062)**
b test	1E-10		1E-10	0.026
b_{sub} test		1E-10		

Panel A in the table reports the results of the principal components analysis carried out for the actual EO spreads, their break process (*bp*) and (normalized) break-free (*bf*) components, obtained from the cubic spline dummy model (DCSM). For each set of series the first row (*tot*) shows the fraction of the total variance explained by each principal component f_i (i=1,...2); the subsequent fifteen rows display the fraction of the variance of the individual series attributable to each f_i. Panel B reports the results of the long memory analysis carried out on the first two principal components (f_i), extracted from the break-free EO spreads using the dummy-spline model (DCSM). In the Table the estimated fractional differencing parameter (*d*), using the Moulines and Soulier (1999) broad band log periodogram estimator, with standard error in brackets is reported. Estimates for the full sample and for the pre-crisis (*pc*) and crisis (*c*) sub samples are reported. "*b test*" is the p-value of the test of equality of the fractional differencing parameter across factors, while "*b_{sub} test*" is the p-value of the test of equality of the fractional differencing parameter across factors and subsamples. "*eq*" for each factor, is the p-value of the test for the equality of the fractional differencing parameter across subsamples.

Table 3: forecast error variance decomposition

		pre-crisis				**crisis**			
	Horizon (days)	***f₁***	***f₂***	***all***	***own***	***f₁***	***f₂***	***all***	***own***
w^{1w}	**1**	2.7	57.1	**59.8**	**40.2**	1.5	12.0	**13.5**	**86.5**
	20	1.8	50.3	**52.1**	**47.9**	27.2	57.8	**85.0**	**15.0**
w^{2w}	**1**	4.5	83.5	**88.0**	**12.0**	4.6	31.2	**35.8**	**64.2**
	20	4.0	83.1	**87.1**	**12.9**	33.9	58.6	**92.4**	**7.6**
w^{3w}	**1**	5.7	82.3	**88.0**	**12.0**	5.9	31.7	**37.7**	**62.3**
	20	4.9	81.1	**86.0**	**14.0**	41.9	52.8	**94.7**	**5.3**
w^{1m}	**1**	10.2	74.0	**84.2**	**15.8**	6.3	15.2	**21.5**	**78.5**
	20	7.8	70.6	**78.4**	**21.6**	63.6	31.2	**94.8**	**5.2**
w^{2m}	**1**	27.6	29.3	**56.9**	**43.1**	14.4	5.9	**20.3**	**79.7**
	20	23.1	25.0	**48.1**	**51.9**	90.0	6.9	**96.9**	**3.1**
w^{3m}	**1**	69.7	3.2	**72.9**	**27.1**	39.9	2.0	**41.9**	**58.1**
	20	67.7	2.9	**70.6**	**29.4**	97.8	0.9	**98.7**	**1.3**
w^{4m}	**1**	86.6	2.6	**89.2**	**10.8**	77.1	0.3	**77.4**	**22.6**
	20	87.1	2.4	**89.5**	**10.5**	99.5	0.1	**99.6**	**0.4**
w^{5m}	**1**	79.1	15.6	**94.7**	**5.3**	89.6	5.8	**95.4**	**4.6**
	20	80.4	14.8	**95.2**	**4.8**	98.7	1.2	**99.9**	**0.1**
w^{6m}	**1**	67.0	29.8	**96.8**	**3.2**	80.2	13.7	**93.9**	**6.1**
	20	68.6	28.5	**97.1**	**2.9**	96.7	3.1	**99.8**	**0.2**
w^{7m}	**1**	61.6	36.5	**98.0**	**2.0**	79.7	19.0	**98.7**	**1.3**
	20	63.3	34.9	**98.2**	**1.8**	95.6	4.4	**100.0**	**0.0**
w^{8m}	**1**	56.4	42.3	**98.7**	**1.3**	75.3	23.7	**99.1**	**0.9**
	20	58.2	40.6	**98.9**	**1.1**	94.2	5.7	**100.0**	**0.0**
w^{9m}	**1**	51.5	47.0	**98.5**	**1.5**	71.6	27.6	**99.2**	**0.8**
	20	53.6	45.1	**98.6**	**1.4**	93.0	6.9	**99.9**	**0.1**
w^{10m}	**1**	45.3	50.2	**95.5**	**4.5**	67.3	31.9	**99.2**	**0.8**
	20	47.8	48.0	**95.8**	**4.2**	91.8	8.2	**100.0**	**0.0**
w^{11m}	**1**	42.3	55.9	**98.2**	**1.8**	63.5	35.9	**99.3**	**0.7**
	20	45.2	53.0	**98.2**	**1.8**	90.6	9.4	**100.0**	**0.0**
w^{1y}	**1**	37.6	58.5	**96.1**	**3.9**	58.8	39.2	**98.0**	**2.0**
	20	41.0	55.1	**96.1**	**3.9**	89.3	10.6	**100.0**	**0.0**

The Table reports for each EO spread the median forecast error variance decomposition at the one-day and twenty-day horizons, obtained from the structural VMA representation of the FI-HFVAR model. For each EO spread series the Table shows the percentage of forecast error variance attributable to each common factor shock (***f₁*** and ***f₂***), together with their sum (***all***). The last column reports the percentage of the forecast error variance attributable to the own idiosyncratic shock (***own***). The results are reported for the various EO spreads maturities available, i.e. from 1-week (w^{1w}) to one-year (w^{1y}), for the pre-crisis (20/06/05 to 8/08/07) and crisis (9/08/07 to 7/04/09) periods.