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THE 2007-? FINANCIAL CRISIS: A MONEY MARKET PERSPECTIVE

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Abstract

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. Our contribution to the ongoing debate on the dynamics of money market spreads is empirical and methodological, motivated by the "shocking" evidence of non-stationary behaviour of money market spreads. In fact, in our view, empirical work assessing the effectiveness of central bank policies has largely overlooked the complexity of the market environment and its implications for the statistical properties of the data. Thus, our main goal is to carefully document both the economic and statistical "fingerprint" of money market turbulence, in the framework of a new econometric framework, carefully accounting for the persistence properties of the data.

Key words: money market interest rates, euro area, sub-prime credit crisis, credit risk, liquidity risk, long memory, structural change, fractionally integrated heteroskedastic factor vector autoregressive model.

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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. There are two dimensions in the debate, one macroeconomic and the other microstructural.[1] The macroeconomic perspective is related to the short-cut approach followed in most macroeconomic models which is to assume that the central bank controls (by whatever means) the interest rate that is relevant, directly, for the investment and consumption decisions of economic agents; or, in more sophisticated macroeconomic models, the assumption that the central bank may be able to steer, via arbitrage arguments, a (single) term structure of interest rates through pricing the expected path of future policy rates plus a term premium (time-varying or not). With a term structure of interest rates in the macroeconomic model both short- and long-term interest rates may affect the investment and saving decisions of economic agents and thereby influence macroeconomic outcomes. However, the recent turbulence in money, credit and financial markets raised some questions about the "controllability" by central banks of the term structure of interest rates. In fact, whilst central banks have generally kept close control of very-short term unsecured money market rates (i.e. for overnight interbank deposits) and were also able to keep a steady influence on some longer-term money market interest rates (e.g. overnight index swap rates and general collateral repo rates), central banks seemed at pains to steer the evolution of the term structure of unsecured money market rates (e.g. EURIBOR anf LIBOR rates), at least in the early stages of the crisis. Still, as the latter rates are those used by investors and other market participants as indexing for derivatives contracts, and by banks to set interest rates on mortgage rates for households and rates on short-term financing for firms' working capital and other longer-term financing, it is those rates that may be of relevance to gauge the monetary policy stance and its appropriateness. Thus, macroeconomic models should in the future be able to incorporate those factors that make it more difficult for central banks to influence the financing costs of the whole economy thereby hampering the transmission mechanism of monetary policy.

This leads to the other side of the controversy which is about the microstructural factors that may explain the (existence and) divergence and instability in the evolution of the interest rates of various money market in-

[1] For a microstructural comprehensive review of the 2007-2009 financial crisis see Acharya and Robertson (2009).

struments (i.e. their spreads). If these spreads are constant, or predictable with a great degree of confidence, the short-cut of considering a single and "controllable" short-end of the term structure of interest rates may be an acceptable simplification for macroeconomic modelling. Indeed, until August 2007 this was the prevailing view that was grounded on solid empirical evidence for the main currency areas over the last decades.

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 (e.g. via Lender of Last Resort - LOLR - intervention) than for addressing solvency issues (which should be addressed by the fiscal authorities). In this debate there are two opposing camps 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 (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 camp 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* that 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).

Our contribution to the ongoing debate on the dynamics of money market spreads is both methodological and empirical and is motivated by the "shocking" evidence of non-stationary behavior of money market spreads. On the methodological side we are 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 financial crisis given its systemic nature.[2] In our opinion, money market spreads are best seen as an *indicator of stress* in the money market, reflecting three inter-related factors: (1) liquidity funding risk; (2) credit / counterparty risk; and (3) investor sentiment / risk appetite / confidence. On the empirical side, it is our view that most empirical work testing the effectiveness of central bank policies has largely overlooked the complexity of the market environment and its implications for the statistical

[2] See Brunnermeier (2009) on the links between liquidity dry-ups and defaults, in the context of the financial crisis.

properties of the data. For example, the empirical analysis in Taylor (2009) relies on the strong correlation between money market spreads and CDS to conclude that the former are a measure of credit risk only, and the effects of central bank actions are tested using dummy variable techniques in obviously misspecified regressions (i.e. with autocorrelated and heteroskedastic residuals). Other authors interpret the residuals of an OLS-type regression of money market spreads on CDS spreads as measuring liquidity risk (see Eisenschmidt and Tapking, 2009). Of course, residuals may capture other factors beyond liquidity risk. Moreover, the non-stationarity of the data and the instability in the estimated parameters are either overlooked or not tested. Thus, our second goal is to carefully document the economic and statistical "fingerprint" of money market turbulence, by means of a novel Fractionally Integrated Heteroskedastic Factor Vector Autoregressive (FI-HFVAR) approach, allowing for an accurate modelling of the persistence properties of the data. Within this framework we provide a decomposition of the EURIBOR-OIS spreads and suggest their economic interpretation.

The remainder of the paper is structured as follows. Section 2 presents the data and reviews the economics of money market spreads in the euro area. Section 3 presents the econometric methodology. Section 4 reports the econometric results on persistence and Section 5 on copersistence. The global dimension of the crisis is illustrated in Section 6. Impulse-response analysis and forecast error variance decomposition are presented in Section 7. Section 8 concludes.

2 Data and modelling issues

In this paper we empirically model the dynamics of the spreads between unsecured inter-bank lending rates and overnight swap rates. In our view EURIBOR-OIS (EO) spreads are *indicators of stress* in the euro area interbank market; EO spreads should reflect three inter-related factors: (1) *funding liquidity risk* which is the risk that a bank may not be able to make cash payments or settle its debts when they fall due; (2) *credit / counterparty risk* which is the risk that a loan may not be paid back and interest payments not received; and (3) *investor sentiment / risk appetite / confidence* which is the willingness of investors to commit funds for risky projects. Moreover, during crisis periods prices may deviate significantly and in a protracted manner from fundamental valuations (e.g. due to limits to arbitrage), quantities may "clear" the market (e.g. rationing due to asymmetric information). Therefore, non-arbitrage models may fail to capture the underlying dynamics of risk factors during systemic crisis periods.

However, even if EURIBOR-OIS (EO) spreads reflected only credit risk, its pricing under risk-neutral conditions based on *intensity models* (see Duffie and Singleton 2003) would require an estimate of the (expected) loss given default; this, in turn, would require estimating the recovery rate of interbank loans and the probability of default of banks, which became immensely hazardous due to uncertainty surrounding the valuation of the assets of the banks, undermining the trust on traditional quantitative and statistical techniques to pricing risks and credit spreads; *structural models* of credit risk pricing would be even more difficuly to estimate.

The EURIBOR, or Euro Interbank Offered Rate, is an average interbank lending rate obtained from inquiring a panel of large banks at which rate they would be willing to offer funds to highly rated banks. Thus, EURIBOR rates are reference rates for uncollateralized lending in Euro. Note that there must not be any effective transaction among banks associated with the reference rates. Indeed, after August 2007 market participants reported that there were virtually no funds traded among banks at term maturities; however, EURIBOR quotes have never been discontinued. This is probably due to the fact that these rates also provide indexing for lending by banks to households and firms and for derivatives contracts (e.g. interest rate futures and options).

The EONIA, or Euro Over Night Index Average, is a quantity weighted average of the rates applied to uncollateralized overnight lending by a panel of large Euro area banks. Thus, the EONIA represents rates with underlying traded volumes. Overnight Index Swaps (OIS) are the fixed rates of swaps contracts for various maturities, whereby one party to the contract pays the fixed rate and in exchange receives the average EONIA over the maturity of the contract. In a swap contract there is no exchange of principal which mitigates counterparty risk. If one party to the contract defaults there is interest rate risk that needs to be covered until the remaining maturity, but there is no pecuniary loss due to default.

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. If the resulting spreads are different from zero it is likely that this is due to counterparty risk, which is priced in the EURIBOR rate but not in the OIS rate.

However, consider for example a three-month OIS contract; a bank with access to the overnight interbank market can borrow daily for three months covering the interest rate risk by paying the fixed leg of the swap contract and receiving the average variable EONIA. The bank will prefer this option to the alternative of borrowing unsecured at EURIBOR if the latter rate is at a large spread against the OIS; if a large number of banks follows this strategy the OIS rate will tend to increase narrowing the spread. Nevertheless, this strategy presupposes that the bank will always be able to borrow the needed funds in the overnight interbank market, exposing the bank to the risk that such liquidity may not be available every day for the next three months, for example, if the bank has a rating downgrade and its credit lines are tightened as a result. Moreover, relying exclusively on the overnight interbank market for funding longer-term assets leads to an extreme maturity mismatch exposing the bank to the liquidity funding risk embedded in such maturity transformation. Thus, liquidity funding risk may, after all, prevent the convergence between the OIS rate and the EURIBOR rate. The EO spread may reflect liquidity risk due to a different channel which is liquidity hoarding when, faced with large uncertainty about the valuation of their own assets and the availability of longer-term funding, banks are led to build up “excess reserves” (for a similar argument see Eisenschimdt and Tapking, 2009).

In addition to these factors EO spreads may reflect swings in investor sentiment or, more generally, the state of investors *confidence*. As emphasized by Akerlof and Shiller (2009) *animal spirits* may have played an important role in the build up and the unfolding of the crisis and, in their view, central bank interventions may be most powerful precisely when market confidence collapses. Moreover, in the context of a *systemic banking crisis* it is very difficult to distinguish financial institutions that are “only” liquidity constrained from those that are insolvent, due to the chain of derivatives contracts and the opacity of interbank linkages and over-the-counter transactions. For all these reasons we consider the various EO spreads as measures of money market stress reflecting the complex interaction between liquidity risk, credit risk and swings in investor confidence. In adition to these considerations the financial crisis exposed the limits to arbitrage (Griffoli and Ranaldo 2009) and the role of asymmetric information (Heider et. al. 2009).

Against this backdrop, 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, we cannot rigorously test whether and where central bank policies made a difference. Second, in essence, 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 of the “real” economy. Third, by accepting as collateral for refinancing, securities that suddenly became illiquid (e.g. ABS) central banks prevented a massive failure of financial institutions worldwide even without increasing the overall liquidity supply; and even if these interventions did not have an immediate and visible impact on money market spreads, they may have prevented the emergence of even higher money market spreads and disorderly conditions in a wide range of financial markets.

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 EO 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.

As shown in Figure 1 (top plots), EO dynamics are telling concerning the size and development of the financial crisis. Two waves of increasing stress (panic) can be detected in the interbank market since the beginning of the crisis. The beginning of the first wave is on August 9 2007, i.e. the day the French bank BNP Paribas revealed its inability to value structured products for three of its investment funds.[3] The crisis triggered interventions by the European Central Bank and the US Federal Reserve, injecting overnight funds of EUR 95 billion and US$38 billion, respectively, on August 9 and August 10 2007. Additional measures were taken by the ECB, the US Federal Reserve and other central banks in the following days.[4] 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.[5] Since September 16, the day after of Lehman Brothers bankruptcy, which can be taken as the starting day for the second wave of magnified money market stress, the spreads climbed rapidly, to reach maximum values in the range of 100b.p. to 233b.p. between October 8 and

[3]While panic started in August 9 2007, just a few days before, on July 31 2007, KfW a German state owned bank provided EUR 8.1 billion in support of the German bank IKB, which was followed on August 1 2007 by the announcement of a EUR 3.5 billion rescue package from the German government. And earlier the US subprime crisis had already been mounting at least since the beginning of 2007, when the 2007-01 BBB- ABX index fell abruptly below par (to about 80) after issuance. The following issue, i.e. the 2007-02 BBB- ABX index, even started trading below par at about 60, evidencing the difficulty in pricing sub-prime risk. Major drops then occurred in August (to 40) and October (to 20) 2007. ABX index price decline has continued through 2008, trading in October 2008 at a value of about 5. Panic was determined by uncertainty concerning the value of the sub-prime collateral. The information problem then translated into uncertainty concerning the value of any structured product offered as collateral in repo transactions, not just residential mortgage-backed securities (RMBS), leading to the freezing of the repo markets.

[4]For a comprehensive chronology of the measures taken by the major central banks and the main market events see Global Financial Crisis Timeline - The University of Iowa Center for International Trade & Development.

[5]See Brunnermeier (2009), ECB (2007) and Ferguson at al. (2007) for an early assessment of the US sub-prime credit crisis. A comprehensive assessment can be found in Acharya and Richardson (2009).

October 13, according to 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, various forms of liquidity injection and unconventional monetary policy measures were taken by central banks, aiming at defreezing the interbank and credit markets, and easing the banking sector from the burden of unperforming loans, as well as to facilitate its recapitalization which has been supported by the intervention of the governments.[6] Starting from December 5 2008, spreads have progressively narrowed, albeit with different speeds across maturities, i.e. at a quicker pace for the shorter maturities. In particular, while the one-, two- and three-week rates have returned to the pre-Lehman Brothers bankruptcy levels by the end of our sample, i.e. April 7 2009, the one-year rate was still 20b.p. above the pre-Lehamn bankruptcy average value at the end of sample.

Not only the level of the spreads, but also their volatility seems to have been affected by the crisis. From Figure 1 (bottom plots) large changes in spread volatility can be noted, from standard deviation values in the range 1.0 b.p. to 1.5 b.p., across maturities, over the pre-turmoil period, to a range of 9 b.p. to 19 b.p. over the first stress wave period, and to a range of 20 b.p. to 45 b.p. over the second stress wave period. Hence, there also appear to be a close and positive association between the level and the volatility of the spreads not only concerning the direction of change (increasing across crisis regimes), but also concerning the timing of change (changes in level and volatility are temporally coordinated). The 20-day moving standard deviations plotted in Figure 1 (central plots) show similar dynamics relative to the spreads in levels. In particular, with reference to the end of the sample, a similar progressive reduction in levels and volatility towards first stress wave's overall levels can be noted.

Overall, the evidence suggests that by April 2009, markets had almost overcome the second wave of stress, but they were still fairly apart from pre-crisis values. Indeed, this finding is fully consistent with the evidence that the financial crisis spilled over to the real economy in the euro area since the fourth quarter of 2008.

3 Econometric methodology

In our empirical analysis, we jointly model the dynamics of the EO interest rate spreads (x_t) according to the following fractionally integrated het-

[6]For a summary of government measures for supporting banking systems in the euro area see ECB (2009 a, b).

eroskedastic factor vector autoregressive (FI-HFVAR) model

$$
\begin{aligned}
x_t &= \Lambda_\mu \mu_t + \Lambda_f f_t + C(L)(x_{t-1} - \Lambda_\mu \mu_{t-1} - \Lambda_f f_{t-1}) + v_t && (1) \\
v_t &\sim iid(0, \Sigma_v) && (2) \\
D(L) f_t &= \eta_t = \sqrt{h_t}' \psi_t, && (3) \\
\psi_t &\sim iid(0, \Sigma_\psi) && (4) \\
M(L)(h_t - w_t) &= [M(L) - N(L)]\eta_t^2 && (5)
\end{aligned}
$$

where x_t is a n-variate vector of long memory processes subject to structural breaks[7], f_t is a r-variate vector of heteroskedastic long memory (in mean (d) and variance (b)) factors ($0 < d_i < 1$, $0 < b_i < 1$, $i = 1, ..., r$), 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 covariance matrix $\Sigma_v = diag\{\sigma_1^2, \sigma_2^2, ..., \sigma_n^2\}$, 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. $C(L) = C_1 L + C_2 L^2 + ... + C_s L^s$, C_j $j = 1, .., $ is a square matrix of coefficients of order n,

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

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

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.

3.1 The reduced fractional VAR form

By taking into account the binomial expansion in (2) and substituting (2) into (1), the infinite order vector autoregressive representation for the factors

[7] See Baillie (1996) for an introduction to long memory processes.

f_t and the series x_t can be written as

$$\begin{bmatrix} f_t \\ x_t - \Lambda_\mu \mu_t \end{bmatrix} = \begin{bmatrix} \Phi(L) & 0 \\ \Phi^*(L) & C(L) \end{bmatrix} \begin{bmatrix} f_{t-1} \\ x_{t-1} - \Lambda_\mu \mu_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{f_t} \\ \varepsilon_{x_t} \end{bmatrix}, \tag{6}$$

where $\Phi^*(L) = [\Lambda_f \Phi(L) - C(L)\Lambda_f]$, $\Phi(L) = \Phi_0 L^0 + \Phi_1 L^1 + \Phi_2 L^2 + ...$, Φ_i, $\forall i$, is a square matrix of coefficients of dimension r,

$$\begin{bmatrix} \eta_t \\ \varepsilon_t \end{bmatrix} = \begin{bmatrix} I \\ \Lambda_f \end{bmatrix} [\sqrt{h_t}' \psi_t] + \begin{bmatrix} 0 \\ v_t \end{bmatrix}.$$

3.2 Estimation

Since the infinite order representation cannot be handled in estimation, a truncation to a suitable large lag for the polynomial matrix $\Phi(L)$ is required. Hence, $\Phi(L) = \sum_{j=0}^{p} \Phi_j L^j$. Then, estimation can be implemented following an iterative procedure consisting of the following steps.

• **Step 1: persistence analysis.** Long memory and structural break tests are carried out on the series of interest in order to determine their persistence properties. Several approaches are available in the literature for structural break testing and estimation, as well as for long memory parameter estimation. See the Section on persistence properties for details.

• **Step 2: initialization.** Conditional on the presence of structural breaks and long memory in the series investigated, an initial estimate of the unobserved deterministic (break processes) and long memory features can be obtained by decomposing the series into their break process (b_t) and long memory components (l_t), i.e. $x_t = b_t + l_t$.

•• Then, the common break processes are estimated by means of Principal Components Analysis (PCA) implemented using the estimated break process $\hat{b}_t$, yielding an estimate of the $m \times 1$ vector of the standardized ($\hat{\Sigma}_{\hat{\mu}} = I_m$) principal components or common break processes $\hat{\mu}_t = \hat{\Lambda}_b^{-1/2} \hat{A}' \hat{b}_t$, where $\hat{\Lambda}_b$ is the diagonal matrix of the estimated non zero eigenvalues of the reduced rank variance-covariance matrix of the (estimated) break processes $\hat{\Sigma}_{\hat{b}}$ (rank $m < n$) and $\hat{A}$ is the matrix of the associated orthogonal eigenvectors.

•• Next, the common long memory factors can be obtained by means of PCA implemented using the estimated break-free series $bf_t = x_t - \hat{b}_t$, yielding the estimate of the r common long memory factors $\hat{f}_t = \hat{\Lambda}_{bf}^{-1/2} \hat{B}' \hat{b} f_t$, where

$\hat{B}$ is the matrix of the estimated orthogonal eigenvectors associated with the r non-zero eigenvalues of the reduced rank variance-covariance matrix of the (estimated) break-free processes $\hat{\Sigma}_{bf}$ (rank $r < n$).

• **Step 3: starting the iterative procedure.** Conditional on the estimate of the deterministic and stochastic factors, the iterative procedure is started by computing a preliminary estimate of the polynomial matrix $C(L)$ and the Λ_f factor loading matrix, by means of OLS estimation of the equation system in (1).

•• Then, a new estimate of the m deterministic factors and their factor loading matrix can be obtained by the application of PCA to the long memory-free series $x_t - \left[I - \hat{C}(L)L\right] \hat{\Lambda}_f \hat{f}_t$.

•• Next, conditional on the new common break processes and their factor loading matrix, the new common long memory factors can be obtained as the first r principal components of the set of break-free processes $x_t - \hat{\Lambda}_\mu \hat{\mu}_t$, and new estimates for the $C(L)$ polynomial matrix and the Λ_f factor loading matrix can also be obtained by means of OLS estimation of the equation system in (1).

•• The procedure described in step 3 is then iterated until convergence.

• **Step 4: restricted estimation of the full model.** Once the final estimates of f_t and μ_t are available , the fractional differencing parameters are estimated for each common long memory factor and their truncated infinite order VAR representation is obtained, i.e. the matrix polynomial $\hat{\Phi}(L)$ is computed from the truncated binomial expansion of the long memory filters. By employing the estimate of the $\Phi(L)$ matrix and the final estimates of Λ_f, Λ_μ and $C(L)$ matrices, the restricted VAR in (6) can be estimated. Following the thick modelling strategy of Granger and Jeon (2004), median estimates of the parameters of interest, and confidence intervals robust to model misspecification, can be obtained by means of simulation methods. We refer to Morana (2009) for details concerning the identification of the common and idiosyncratic shocks, which can be performed by means of a double Choleski approach, and the computation of impulse response functions and forecast error decomposition.

• **Step 5: conditional variance analysis.** Median factor estimated residuals can be firstly computed using the estimated median (me) parameters, i.e.

$$\hat{\eta}_t = \hat{f}_t - \hat{\Phi}(L)^{(me)} \hat{f}_{t-1}$$

Then, an A-FIGARCH version of the O-GARCH model of Alexander and Chibumba (1996) and Alexander (2002) is implemented. The latter consists of the following steps. Firstly, the model is estimated for each of the factor residual series and the conditional variance process computed (h_t). Secondly, consistent with the assumptions of conditional and unconditional orthogonality of the factors, the conditional variance ($H_{x,t}$) and correlation ($R_{x,t}$) matrices for the actual series may be computed as

$$H_{x,t} = \Lambda_f H_t \Lambda_f',$$

where $H_t = diag\{h_{1,t}, h_{2,t}, ..., h_{r,t}\}$, and

$$R_{x,t} = H_{x,t}^{*-1/2} H_{x,t} H_{x,t}^{*-1/2},$$

where $H_{x,t}^* = diag\{h_{x_1,t}, h_{x_2,t}, ..., h_{x_n,t}\}$, respectively.

3.2.1 Asymptotic properties

Recent theoretical results validate the use of PCA in the case of both weakly (Bai, 2003) and strongly (Bai, 2004; Bai and Ng, 2004) dependent processes. In particular, Bai (2003) establishes consistency and asymptotic normality of PCA when both the unobserved factors and the idiosyncratic components show limited serial correlation, and the latter also display heteroskedasticity in both their time-series and cross-sectional dimensions. In Bai (2004) the above results (consistency and asymptotic normality) are extended to the case of I(1) unobserved factors and I(0) idiosyncratic components, also allowing for heteroskedasticity in both the time-series and cross-sectional dimensions of the latter component. Moreover, Bai and Ng (2004) have established consistency also for the case of I(1) idiosyncratic components. As pointed out by Bai and Ng (2004), consistent estimation should also be achieved by principal components techniques in the intermediate case of long-memory processes, and Monte Carlo results reported in Morana (2007) provide supporting small (cross-sectional) sample empirical evidence for PCA in the latter framework. Finally, PCA based estimation of common non linear deterministic components from a set of estimated individual non linear deterministic components has also been advocated by Bierens(2000).[8]

The proposed estimation procedure is multi-step, but iterated to improve efficiency, based on the use of consistent and asymptotically normal estimators[9] of the fractional differencing parameter (semiparametric or parametric estimators) and the weakly dependent part of the model (the OLS estimator). Moreover, the model could also be estimated without fractional prefiltering, by relying on the infinite order VAR representation of the VARFIMA structure of the $D(L)$ matrix, leading to standard stationary polynomials in the lag operator, with all the roots outside the unite circle.

[8] Yet, details cannot be found in the published version of his paper.

[9] In some cases also asymptotically efficient.

Although a formal proof is beyond the scope of this paper, it is conjectured, therefore, that the proposed estimation procedure leads at least to consistent estimation of the parameters and quantities of interest.

4 Persistence properties

The large and persistent changes in the mean and volatility levels of the spreads are indicative of structural breaks in their mean and variance components. As other forms of persistence are plausible, in addition to breaks, i.e. long memory or stochastic persistence, a modelling framework allowing to account for both features, and to distinguish among them, should be employed. The Dolado et al. (2004) structural break test (DGM 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 (BP, 1998) test has been employed in order to gauge evidence on the number and location of break points. On the other hand, the Moulines and Soulier (1999) broad band log periodogram (BBLP) estimator[10] has been employed to assess the degree of fractional integration of the actual and break-free EO spreads.

4.1 Methodological details

The results of the BP tests are reported in Table 1, Panel A. As is shown in the Table, the evidence points to two break points with similar location across maturities, occurring between August 9 and August 16 2007 the former, and on September 16 2008 the latter. Hence, the selected break points can be related to the starting days of the two *stress waves*, i.e. August 9 2007 and September 16 2008.[11] Very large absolute and relative increase in the mean of the spreads, i.e. in the range 48% to 255%, according to maturity

[10]The Moulines and Soulier (1999) broad band log periodogram estimator yields an estimate of the fractional differencing parameter (d) from OLS estimation of the regression $\ln(\exp^{-\psi(m)}\sum_{J_k} I_n(\lambda_j) = d(-2\log\lambda_k) + \sum_{i=0}^{p}[\gamma_i \frac{\cos(i\lambda_k)}{\sqrt{\pi}} + v_t$, where $\lambda_j = 2\pi j/n_m$, $j = 1,...,n/2$, m is the size of the nonoverlapping blocks for periodogram ($I_n(\lambda_j)$) averaging, $n_m = 2m[n/2m]$, $K_n = n/2m$, $k = 1,...,K_n$, $J_n = \{m(k-1)+1,...,mk\}$, $\lambda_k = (2k-1)\pi/2K_n$, $\psi(m)$ is the digamma function. Under some conditions it follows that $\sqrt{\frac{n}{p_n}}\left(\hat{d}_{p_{n,m}} - d\right) \xrightarrow{d} N(0, m\psi'(m)$. The order of the cosine expansion is determined by means of Mallow's C_L criterion, while a choice of $m = 4$ is suggested in Moulines and Soulier (1999).

[11]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.

(88% on average across maturities), and 9% to 32% (16% on average across maturities), can be noted for the selected dates, respectively. Moreover, also December 5 2008 could be selected as additional break point, and associated with the 75b.p. cut announced on December 4 2008 by the ECB and implemented on December 10 2008. In addition to a sizeable contraction in the EO spreads, in the range -11% to -31% (-16% on average), also a reversal in the EO spreads trend can be observed. Starting with December 5 2008, spreads have steadily decreased, converging towards first stress wave levels. 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 test. Implementation within the DGM testing framework, however, suggest that the additional selected break point, as well as the changing slope structure, is appropriate for the data investigated (results are discussed below).

Hence, concerning the structure of the candidate break process three modelling strategies have been implemented. The first strategy allows for an abrupt change in the level of the modelled variables (dummy model, DM). The break points have been selected according to the BP test, also allowing, after additional testing (using the DGM test), for a changing slope structure and for a break occurring on December 5 2008. Moreover, a flexible Fourier functional form (Gallant, 1984; FFM) and a cubic spline smoother (CSM) approach have also been employed which do not require any assumption on the exact timing and number of break points (see Enders and Lee, 2004; Baillie and Morana, 2009; Engle and Rangel, 2008), allowing for a smooth transition across regimes, as well as for a time-varying mean level within each regime. A dummy model with smooth (spline) transitions across regimes (DCSM) has finally also been employed. The latter model allows for additional flexibility relatively to the standard dummy model, and it seems particularly suited for the data at hand, where relatively large changes in the level of the variables occur consecutively in the range of few days, rather than in just a single day. Also in the spline-dummy specification a broken trend component has been included.

In addition to the mean component, 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, less clear-cut is whether a further increase in long-term volatility occurred following the spreading of the second stress wave. As is shown in the Table, the location of the break points would be similar to what was found for the mean of the process, with breaks occurring around August 9 2007 and September 16 2008. Yet, the selection of the latter break point is not robust to the selection method employed.[12] Hence, after some experimentation, a single break point, i.e. August 9 2007, has been retained for the rest of the analysis.

The following break process specifications have then been employed:

$$bp_t = \begin{cases} \alpha_0 + \alpha_1 D_{1,t} + \alpha_2 D_{2,t} + \alpha_3 D_{3,t} + \alpha_4 D_{4,t} & \text{DM} \\ \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3 + \sum_{j=1}^{K} [\gamma_j \sin(2\pi jt/T) + \delta_j \cos(2\pi jt/T)] & \text{FFM} \\ f_p(t) & \text{CSM} \\ (\alpha_0 + \alpha_1 D_{1,t} + \alpha_2 D_{2,t} + \alpha_3 D_{3,t} + \alpha_4 D_{4,t}) \sqcup f_p(t) & \text{DCSM} \end{cases},$$

where $t = 1, ..., T$, $T = 992$, D_1 is a (first stress wave) step dummy variable with unity value over the period August 9 2007 to April 7 2009 included, D_2 is a (second stress wave) step dummy variable with unity value over the period September 16 2008 to April 7 2009 included, D_3 is a (second stress wave) broken linear trend variable, with non-zero values over the period September 16 2008 to December 4 2008 included, D_4 is a (stress resolution) broken linear trend variable, with non-zero values over the period December 5 2008 to April 7 2009 included, K is the order of the trigonometric expansion of the Fourier flexible functional form, while the objective function for the determination of the smoothing parameter p for the spline specification is

$$S(p) = p \sum_t (x_t - f(l_t))^2 + (1-p) \int f''(l_t)^2,$$

where x_t is the generic interest rate spread to be smoothed, l_i defines the position of knots, $\int f''(t)$ is the integrated squared second derivative of the cubic spline function $f(l) = a_i + b_i l + c_i l^2 + d_i l^3$. See Silverman (1985) for details on estimation. Differently, for DM and FFM OLS estimation is performed, while DCSM requires 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.

In Figure 1 (bottom plots) the estimated break processes, obtained by means of the different methods, are plotted for the 1-week and 1-year maturities. As shown in the plot, all methods yield similar estimates of the candidate break processes, with, FFM and CSM implying a smoother transition across regimes. Yet, as revealed by the BP test, the transition across regimes was fairly abrupt, requiring few working days to be completed. The

[12] The modified BIC criterion (LWZ) points to a single break point occurring on August 9 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.

DCSM specification can be retained as the preferred specification among the four, as it allows for a quicker transition across regimes than CSM and FFM, still however avoiding a one-step change as for DM. However, as it will be discusses below, the results of the persistence analysis are robust to the actual selection of the break process.

Finally, the DGM test is implemented by means of the Dickey-Fuller type auxiliary regression

$$\Delta^d y_t = \Delta^d bp_t^* - \phi bp_{t-1}^* + \phi y_{t-1} + \sum_{j=1}^{s} \Delta^d y_{t-j} + v_t, \tag{7}$$

where bp_t^* is the estimated candidate break process from any of the four models employed, $v_t \tilde{} iid(0, \sigma_v^2)$. The null hypothesis of I(d), i.e. pure long memory, implies $\phi = 0$, while the alternative of I(0) stationarity plus structural change implies $\phi < 0$. Critical values have been computed, case by case, by means of simulation assuming two scenarios for the long memory process $\phi(L)(1-L)^d y_t = \varepsilon_t$, $\varepsilon_t \tilde{} iid(0, \sigma_{\varepsilon,t}^2)$ under the null. The first scenario (I) assumes that $\sigma_{\varepsilon,t}^2 = \sigma_\varepsilon^2$, $t = 1, ..., 992$, i.e. unconditional homoskedasticity. On the other hand, the second scenario (II) assumes unconditional heteroskedasticity, with $\sigma_{\varepsilon,t}^2 = \sigma_{\varepsilon,1}^2$, $t = 1$ (20/06/05), ..., 588 (08/08/07) and $\sigma_{\varepsilon,t}^2 = \sigma_{\varepsilon,2}^2$, $t = 589$ (09/08/07), ..., 992 (07/04/09). The values of the parameter employed in the simulations were set according to the properties shown by the investigated series. The lag order s in the auxiliary specification was finally selected by means of the AIC criterion, allowing for up to five lags.

4.2 Results for the DCSM specification

In Table 1 the results of the persistence analysis are reported[13]. According to the BBLP estimator, strong (non stationary) long memory can be found in the actual EO spreads, with an average estimated fractional differencing parameter of about 0.94 (0.041). A Bonferroni bounds test does not allow to reject the null of equal fractional differencing parameter across EO spreads for the actual series (the minimal p-value across the 110 possible bivariate tests is 0.002, to be compared with a 5% critical value equal to 5E-4). Sizable long memory can also be found in the break-free series yield by the various specifications in, the range 0.24 to 0.64 (0.40 (0.041) on average) for the DCSM approach. A hump-shaped profile can be noted in the cross-section of

[13] Due to the potential break in the unconditional variance of the EO spreads, the estimates of the long memory parameter for the break-free series are obtained from standardized procesess, using the selected regimes for the unconditional means and variances of the spread processes.

persistence, the latter increasing with maturity up to the three-week horizon and decreasing thereafter.[14] A Bonferroni bounds joint test yields clear-cut rejection of the null of equal fractional differencing parameter for the break-free series across all the maturities, the latter results being due to stronger persistence at the shortest end of the term structure, while similar persistence can be found for consecutive maturities.

The finding of significant long memory in both the actual and break-free specifications points to non spurious structural change in the EO spreads, as, otherwise, evidence of overdifferencing, i.e. a negative estimate for the fractional differencing parameter, would be expected (see Granger and Hyung, 2004). The DGM test supports the latter conclusion, pointing to significant break processes for all of the EO spreads, as the null of pure long memory process is rejected in all of the cases, at the 5% significance level (a zero lag order ($s = 0$) was the selected optimal order by the AIC criterion for the DGM auxiliary equation).

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 (the p-value is 1E-9 in both cases) and maturity by maturity pairwise comparison.

5 Copersistence properties

The analysis in the previous section documents the dramatic change in the economic determinants of the EO spreads after August 9 2007. In fact, the Euro area money market changed from an environment that generated stationary EO spreads, which could be modelled by mean-reverting random changes around a constant (and small) unconditional mean, to an environment of *unpredictable* changes in EO spreads, modelled, in our framework, as non-stationary (long-memory) processes, with the non-stationarity feature due to structural breaks in the mean and variance of the processes, occurring with changes in levels, slope and persistence. The latter time series features

[14] Similar results have been obtained by the application of the other break process estimation approaches, which, for reasons of space, are not reported. Overall, FFM and CSM point to stronger persistence in the break-free series than DM and DCSM. The finding may suggest that the former two approaches are not fully satisfactory in capturing the evolution of the break process for the data at hand, so that the excess persistence found may depend on some structural change still left in the data. This is also in the light of the fact that DM and DCSM do not lead to antipersistence in the break-free series. Detailed results are available upon request from the authors. PLEASE SEE APPENDIX A FOR REFEREEING PURPOSES.

challenge the existing financial models which, to a large extent, have been developed around mean-reverting processes for interest rates, credit spreads (with or without jumps), and risk factors (see Duffie and Singleton, 2003).

However, if the dynamics of the whole term structure of EO spreads could be decomposed into just a few underlying common factors, an economic interpretation of the EO spreads would still be feasible. Thus, in this section we assess the presence of commonalities in the EO spreads, using principal components analysis (PCA), which, as discussed in the methodological section, is motivated by recent theoretical and simulation results concerning the application of PCA for strongly persistent and non stationary processes. As shown in Table 2, indeed strong evidence of commonalities can be detected in the actual EO interest rate spreads. In fact, a single principal component explains about 99% of total variance, also accounting for over 95% of the variance of each of the EO spreads from the 2-week maturity onwards.

5.1 Cobreaking and common long memory factor analysis

By isolating the break process component from the long memory component, as shown in Table 2, independently of the break process modelling strategy implemented, over 99% of total variance for the break process components is explained by the first principal component. The latter also accounts for over 95% of the variability of the break process for each of the maturities, apart from the shortest one. Yet, also for the latter the proportion of explained variance is never lower than about 90%. Therefore, the selection of a single common break process for the spreads is a clear-cut finding (Figure 2, top plot).

Turning to the long memory components, as shown in Table 2, it is found that over 80% of total variance is accounted by the first two principal components (65% and 18%, respectively) for the DCSM break-free series, with the former affecting all the maturities, but the latter accounting for the bulk of variance for maturities within 1-month (41% to 63%). Independently of the break modelling strategy, higher order principal components mainly capture idiosyncratic features, pointing therefore to a clear-cut selection of two common long memory factors.[15] In terms of persistence properties, as shown in

[15]Essentially the same results are obtained for DM, while for FFM and CSM the proportion of total variance accounted by the first principal component is larger, i.e. about 80%. Moreover, for FFM and CSM the first principal component is dominating also at the short end of the term structure (26% to 78% within 1-month). Detailed results are avaiable upon request from the authors.

Yet, some interesting differences can be noted for the two categories of models, i.e. the

Table 3 and Figure 2 (central plots), the two stochastic factors show the long memory feature, with estimated fractional differencing parameters consistent with the findings for the break-free series. In fact, the estimated fractional differencing parameters are 0.320 (0.041) and 0.516 (0.041) for the first and second principal component, respectively, and 0.418 (0.041) on average. Subsample (pre-crisis and crisis) estimation and testing points to a significant increase in persistence following the unfolding of the crisis (Table 3, 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.[16] The discontinuity in persistence can easily appreciated in Figure 3, showing a sizable increase in persistence following August 9 2007 (observation 559), as the common long memory factors appear to be much smoother than before.

Finally, anticipating some of the results obtained through the estimation of the FI-HFVAR model, both long memory and structural change can be detected also in the volatility of the estimated common long memory factors. Long memory in variance is however not strong, with estimated fractional differencing parameters of about 0.10 and 0.23 for the first and second common long memory factors, respectively.[17] As is shown in Figure 2 (bottom plots), the change in the level and range of variation of the conditional standard deviation process, after the unfolding of the crisis, is remarkable (a four fold increase). Both similarities and differences can be detected across factors. For instance, for both factors the increase in volatility was particularly strong at the outset of the crisis in August 2007, requiring up to two

dummy models (DM and DCSM) on the one hand, and the flexible/spline models (FFM and CSM) on the other hand. In fact, while for the former category of models the second factor (the one closely associated with the shortest end of the term structure of EO spreads) is the most persistent one, the opposite can be noted for the second category of models. Given the persistence properties shown by the break-free series (the shortest maturities being more persistent than the longest ones), it can be concluded that the common long memory factors extracted from the DM and DCSM break-free series are more likely to offer an accurate description of the persistent dynamics in risk spreads.

[16] The $0.5 \leq d < 1$ case is often referred as the non stationary, yet mean reverting, long memory case. The mean reversion property depends on the fact that the effects of shocks eventually dye out, i.e, provided $d < 1$, the sequence of impulse response weights converges to zero asymptotically.

[17] Adaptive FIGARCH(1,d,1) models, with cubic spline dummy intercept component for the conditional variance equation have been estimated for both (final) common long memory factors. Estimation is performed directly on the common factor residuals obtained through filtering using median estimated parameters, as described in the methodological section.

months to stabilizing about the new higher levels. Further instability can be detected, around December-February 2008, for the second factor. Finally, an additional increase in volatility can be detected for both factors following Lehman bankruptcy in mid September 2008. For both factors the reversion to pre-Lehman volatility levels is already evident starting from mid December 2008, possibly associated with the commitment of the ECB to ensure a smooth working of the money market, using all the available tools, as witnessed by the progression of interest rate cuts, reinforcing the excess liquidity creation achieved by the full allotment policy.

5.2 A suggested economic interpretation

The empirical evidence on the cobreaking and copersistence properties of the EO spreads suggests the following economic interpretation of their dynamics.

Level factor of credit spreads Firstly, the long-term evolution of EO spreads is very similar across maturities, as a single common break process explains over 90% of the variance for each maturity. Hence, this component captures the *level* of EO spreads in the crisis period reflecting, among other factors, *confidence (risk appetite)*. In fact, as shown by the structural break analysis, the break process in the EO spreads can be related to the two waves of increasing bank stress, and a third break point, following the announcement of the larger than expected rate cut by the ECB, when a declining trend in the levels of the EO spreads started. The evidence on break points 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.[18] As shown in Figure 3, the increasing common break process component (top plot) indeed reflects the timing of the banking crisis; its 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), which was reinforced by the full allotment policy started in October 2008 that led to a situation of excess liquidity in the money market (middle plot). 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). The full allotment-fixed rate policy generated

[18] 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.

a liquidity surplus that led to systematic and large recourse to the deposit facility of the Eurosystem as illustrated in Figure 3 (after observation 863, middle plot).[19] This illustrates the intermediation role played by the ECB as it was simultaneously providing credit to the banking system and taking deposits from it. However, note that towards the end of the sample period (after observation 900), while the common break process 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 EO 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 EO spreads.

Curvature factor of credit spreads Secondly, the medium-term evolution of the EO spreads shows two distinct dynamics. The first common long memory factor (principal component) accounts for dynamics which are common to all the EO spreads; however 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 credit spreads during the crisis period. As illustrated in Figure 4 (top plot) the peaks in this component coincide with moments when the major central banks announced coordinated actions, in particular announcements on US$ 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 (e.g. ECB, Bank of England and Swiss National Bank). The US dollars were provided by the US Fed to the European central banks via bilateral swap lines. Note that after each of the three major announcements highlighted by vertical bars in Figure 4 (top plot) this component of EO spreads either declined sizably or stabilised, suggesting some effectiveness of the measures in alleviating money market tensions.[20] In fact, the cross correlation analysis suggests that the an-

[19] *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.

[20] 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

nouncents on coordinated actions are positively correlated to developments in the first common long memory factor (Figure 4; middle panel left hand side plot). Other cross-correlations were calculated between the first common long memory factor and ECB fine-tuning operations (FTO) (Figure 4; middle panel right hand side plot), the share of longer-term refinancing operations in total refinancing volume (LTRO/Total) (Figure 4; lower panel left hand side plot) and the daily reserve surpluses[21] (DRS) (Figure 4; lower panel right hand side plot) only the cross-correlation with the ratio LTRO/Total is statistically significant. In fact, the dark bars illustrate the negative correlation between the first common long memory component and the contemporaneous and lagged values of the ratio LTRO/Total. This suggests 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 credit spreads, in particular, between the three and six months maturities (a kind of "curvature effect").

Slope factor of credit spreads The second long-memory factor mainly explains dynamics common to the shortest end of the EO spreads term structure. This feature is reminiscent of a *slope factor* capturing the medium-term evolution in the credit spreads during the crisis period. This *slope* factor may capture a "pure" liquidity risk component. Interestingly as illustrated in Figure 5 (top plot) there seems to be a close correlation during the crisis between this component and large volume fine-tuning operations conducted by the ECB. Note that negative fine-tuning operations (FTOs) 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 suggest that the former captures movements in the EO spreads associated to shorter-term liquidity imbalances that are being "corrected" by the ECB as further illustrated by the cross-correlation analysis (Figure 5; middle panel right hand side plot). Other cross-correlations were calculated between the second common long memory factor and coordinated announcements (Figure 5; middle panel left hand side

(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 from the US Fed to the ECB.

[21] DRS measures the daily deviation of banks' current accounts with the Eurosystem from their daily average reserve requirement. During the crisis DRS became systematically large and positive at the beginning of the reserve maintenance period and large and negative towards the end of the reesrve maintenance period leading to an early fulfilment of the minimum reserve requirement (so-called *frontloading*).

plot), the share of longer-term refinancing operations in total refinancing volume (LTRO/Total) (Figure 5; lower panel left hand side plot) and the daily reserve surpluses[22] (DRS) (Figure 5; lower panel right hand side plot). The cross-correlation between the second long memory component and the ratio LTRO/Total is statistically significant and positive especially for lagged values of LTRO/Total. This suggests that 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 credit spreads at the very short-end of the money market curve, in what looks like a substitution (slope) effect.

6 Some issues related to the global dimension of the crisis

The evidence discussed so far is related to the Euro area money market. Yet, the persistent features uncovered are not peculiar to the Euro area and, due to the global nature of the crisis, are likely to be shared by major financial markets. For comparison and robustness assessment, the persistence analysis has been repeated using the whole term structure for the US dollar LIBOR-OIS (LO) spreads, i.e. the one-week and two-week maturities and the one-month through the one-year maturities.[23]

Overall the findings for the LO spreads are strongly consistent with the results for the EO spreads, along all the dimensions considered by the persistence and copersistence analysis:

• spreads are strongly persistent: the average fractional differencing parameter is about 0.93 (0.041); persistence is accounted for by both long memory and structural breaks;

• structural breaks: the location of the break points is similar to what was found for the euro area, i.e. large change in the mean and volatility of the spreads have occurred in correspondence of unfolding of the two stress-waves;

• cobreaking: independently of the break model, a single common break process accounts for almost 100% of total variance for the break process components across maturities (Figure 6, top plot); the latter factor accounts

[22] DRS measures the daily deviation of banks' current accounts with the Eurosystem from their daily average reserve requirement. During the crisis DRS became systematically large and positive at the beginning of the reserve maintenance period and large and negative towards the end of the reesrve maintenance period leading to an early fulfilment of the minimum reserve requirement (so-called *frontloading*).

[23] For reasons of space detailed results are not reported, but are available upon request from the authors.

for over 90% of total variance for each spread with maturity beyond two months; for maturities within one month the percentage of explained variance is in the range 65% to 78% for the selected DCSM model;

• long memory: strong evidence of long memory in the break-free series can also be found. The average figure from the DCSM model is 0.493. The degree of persistence is not constant along the term structure, being higher for shorter maturities than for longer ones;

• common long memory factors: two common long memory factors are sufficient to account for almost 100% of total variance (Figure 6 middle and bottom plots); the first factor (curvature factor) affects all the maturities, with impact weakest at the very short end of the term structure (below 55% within the 1-month maturity) and strongest at medium- long term maturities (over 80%); the second factor (slope factor) is on the other hand strictly related to the shortest end of the term structure (about 45% on average within the 1-month maturity);

• the crisis has determined a significant increase in the persistence of the two common long memory factors, i.e. about 70% and 50% for the first and second factors, respectively. The transition from stationary to non stationary long memory is also detected as a consequence of the crisis, albeit LO spreads appear to be relatively more persistent than EO spreads before the setting in of the crisis, but relatively less persistent over the crisis. Hence, the latter finding suggests that shocks may have a more long lasting impact in the Euro area than in the US. Also the normalization of the interbank market may then occur more quickly in the US than in the Euro area, as, following the correction in the long-term level, break-free spreads would adjust more rapidly in the US than in the Euro area.

By comparing the common permanent and persistent components extracted from Euro area and US data, a close positive association between the common break process components can be noted, with correlation coefficient, over the crisis sample, equal to 0.96. A positive linkage, yet of weaker intensity, can also be detected for the two common long memory factors, with full sample correlation coefficient equal to 0.29 and 0.50, for the first and second factors, respectively; comovement appears to be stronger over the crisis period than the pre-crisis period for the first factor (the correlation coefficients are 0.39 and 0.19, respectively), while comovement is of similar intensity for the second factor (the correlation coefficients are 0.44 and 0.51, respectively).

Overall, the findings are consistent with the view that the global dimension of the crisis is captured by the permanent/long-term (common break process) component of the risk spreads, while the common long memory factors describe more idiosyncratic national-level adjustment dynamics. Interestingly, according to estimates, while risk factors in the US and the euro area were very close over the pre-crisis period, i.e. the EO-LO spread was about -3.2bp, over the first stress wave (August 9th 2007 to September 15th 2008) a reversal took place, with the EO-LO spread having averaged at about 12bp. Again a reversal took place in the aftermath of the second stress wave, with the EO-LO spread having been negative (-28bp on average) for most of the second stress wave period. The findings have interesting implications concerning the direction of contagion across the Euro area and the US money markets. While the first stress wave started with bad Euro area news - on August 9 2007 the French bank BNP Paribas revealed inability to value structured products for three of its investment funds-, the second stress wave started with bad US news -on September 15 2008 the US bank Lehman Brothers went to bankruptcy. From the sign of the EO-LO spread, at least in its aftermath, the relative importance of the shock across countries can be gauged, as well as the direction of international contagion.

7 The FI-HFVAR model

In the light of the results of the persistence and co-persistence analysis, pointing to a single break process and two common long memory factors, the dimension of the FI-HFVAR model is seventeen equations, corresponding to the fifteen money market EO spreads plus the two common long memory factors. On the basis of the detected instability in the persistence parameter, the model has been estimated by allowing the fractional differencing parameter to take different values for the pre-crisis and crisis periods, consistent with the findings of the persistence analysis (Table 2).[24]

Following the thick modelling strategy of Granger and Jeon (2004), 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 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.

Interest rate spread series have been ordered from the shortest to the longest maturities; given the orthogonality of the factors and the assumed

[24] The values employed are 0.24 and 0.44, for factor 1 and 2, respectively, over the pre-crisis period; on the other hand, figures for the crisis period are 0.89 and 0.87, respectively; for the actual series the values employed are 0.44 and 0.89 for the pre-crisis and crisis period, respectively. The selection of the latter values for the actual series follows from the property of integrated process, according to which the order of integration of a linear combination of non cointegrated processes is determined by the order of integration of the most persistent process.

lack of spillover of idiosyncratic shocks, the latter ordering is immaterial for the computation of the impulse response functions and the forecast error variance decomposition. Consistent with the breaks in the unconditional variance of the EO spreads detected by the persistence analysis, the unconditional variance-covariance matrix employed for the policy analysis has been allowed to change according to the sub period (pre-crisis/crisis) investigated.

7.1 Forecast error variance decomposition and impulse response analysis

As shown in Table 3, the findings of the forecast error variance decomposition are clear-cut.

Firstly, independently of the maturity, the contribution of the common factor shocks to fluctuations is similar for both horizons over the pre-crisis period, i.e. 57% to 92% at the 1-day horizon and 48% to 99% at the 20-day horizon; 90% on average for both cases; differently, over the crisis period the common shocks are always dominating at long horizons (85% to 100% at the 20-day horizon; 98% on average), yet dominating at short horizons from the 4-month maturity onwards only (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, the first factor, i.e. the *curvature* factor, over the pre-crisis period, 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, for 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 7, 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 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 EO spreads. For instance, over the pre-crisis period, the *curvature* shock has a five fold larger impact on the 1-year EO spread than on the 1-week EO 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 EO 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.

8 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 EURIBOR-OIS spreads in the framework of a new econometric approach. Not surprisingly the main findings are that most of the non stationarity in the EURIBOR-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 the credit risk, liquidity risk and confidence. Deviations of the EURIBOR-OIS spreads from their long-term (time-varying) values tend to be corrected slowly due to their long memory feature. We found that the increasing trend in the EURIBOR-OIS spreads was broken and reversed after the ECB cut its key policy rate by 75 bps, a move that took markets by surprise (i.e. the cut was larger than the markets expected). This, together with other policy measures, like the policy of full allotment at a fixed rate in all refinancing operations, including longer-term maturities, a policy extended to 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. Overall, our findings are consistent with the global dimension of the crisis, given the similar features uncovered for the US money market during the crisis, and the strong correlation found for the common break processes in the euro and US dollar spreads. An important question left open is when the crisis will be over. After the crisis the money market will not necessarily return to pre-crisis features. While it could be expected a reduction in persistence to stationary long memory, i.e. mean reverting spreads, as well as a sizable contraction in volatility, the level of the spreads might not come back to pre-crisis values. Surely a peculiar feature of the pre-crisis Euro area, but also US, money market, was the virtual absence of credit spreads. As a consequence of the crisis sizable credit spreads became a feature of the money market. Whether it will remain in the future is an open question.

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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*	bf_{DCSM}	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**	
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)	f_1	f_2	*all*	*own*	f_1	f_2	*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 ($\boldsymbol{f_1}$ and $\boldsymbol{f_2}$), 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.

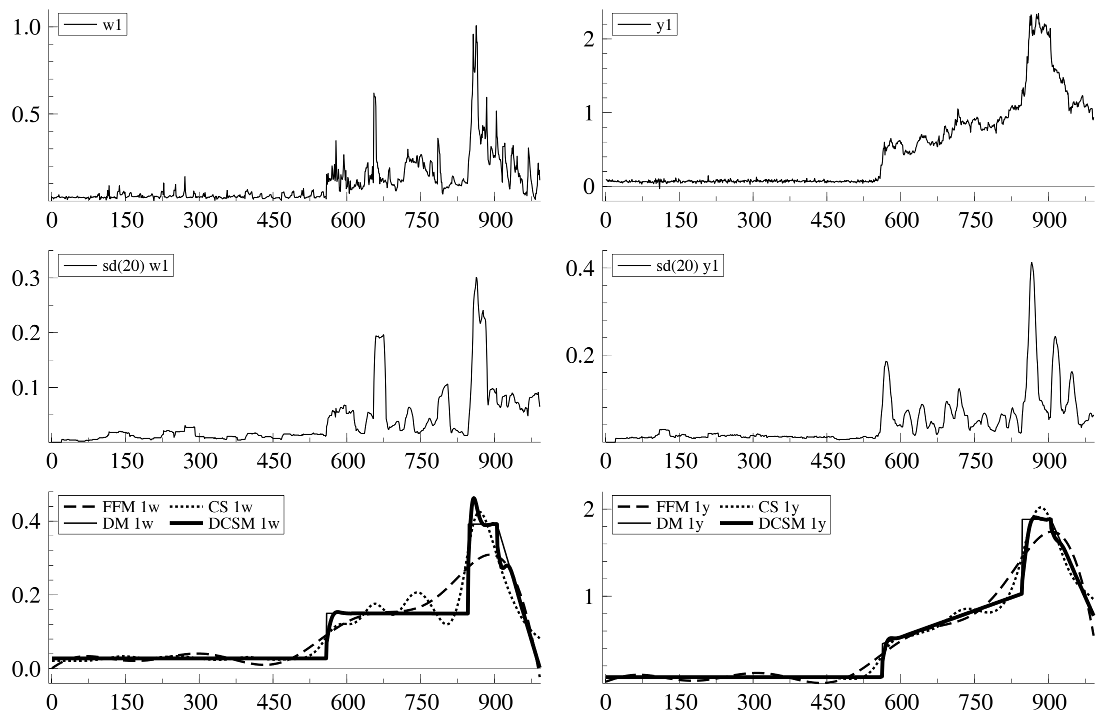

Figure 1: EURIBOR-OIS spreads (top plots), 20-day moving standard deviations (central plots), and estimated break processes (bottom plots) for the 1-week (w1) and 1-year (y1) maturities. The estimated break processes are from the dummy model (DM), the flexible Fourier model (FFM), the cubic spline model (CSM), and the dummy-spline model (DCSM).

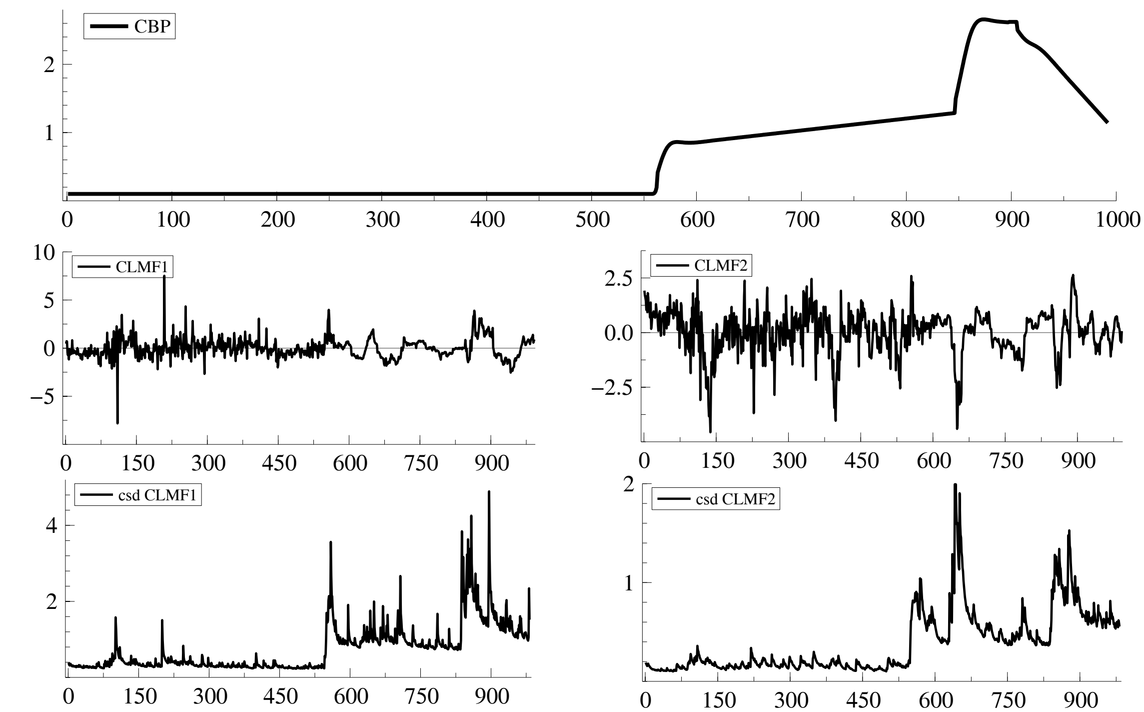

Figure 2: EURIBOR-OIS spreads; common break process (CBP), (normalized) common long memory factors (CLMF) and common volatility factors (csd CLMF) from the dummy-spline model (DCSM).

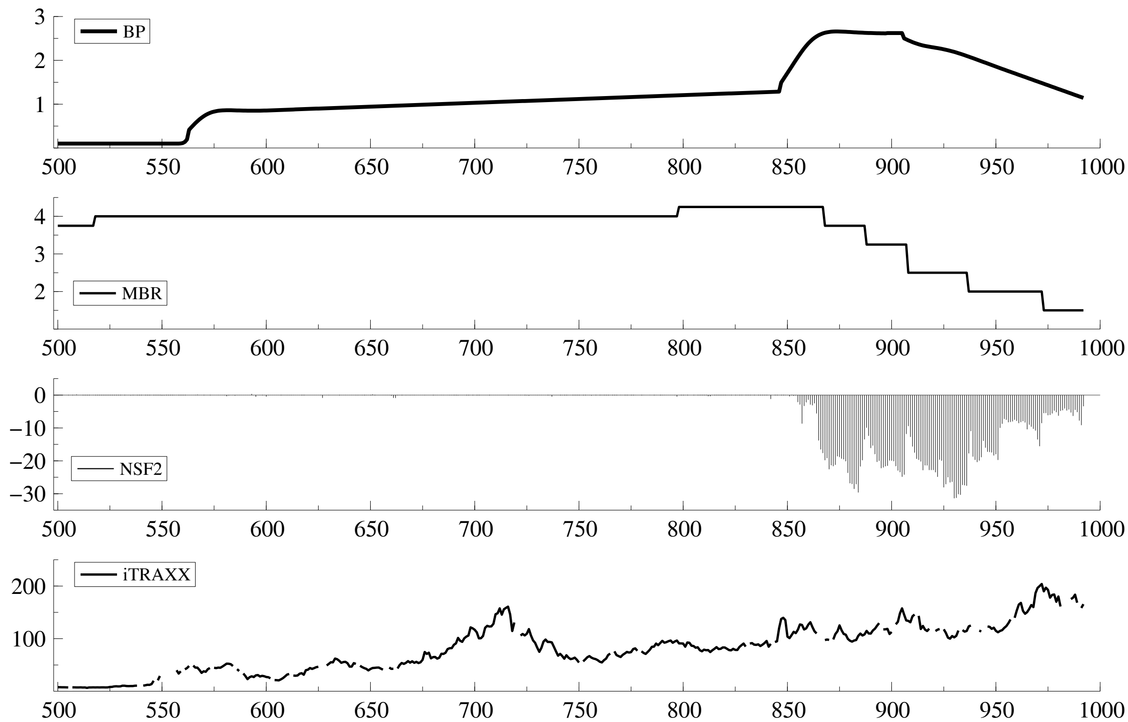

Figure 3: Common break process (CBP), minimum bid rate (MBR), net standing facilities (NSF) and iTRAXX Financials index.

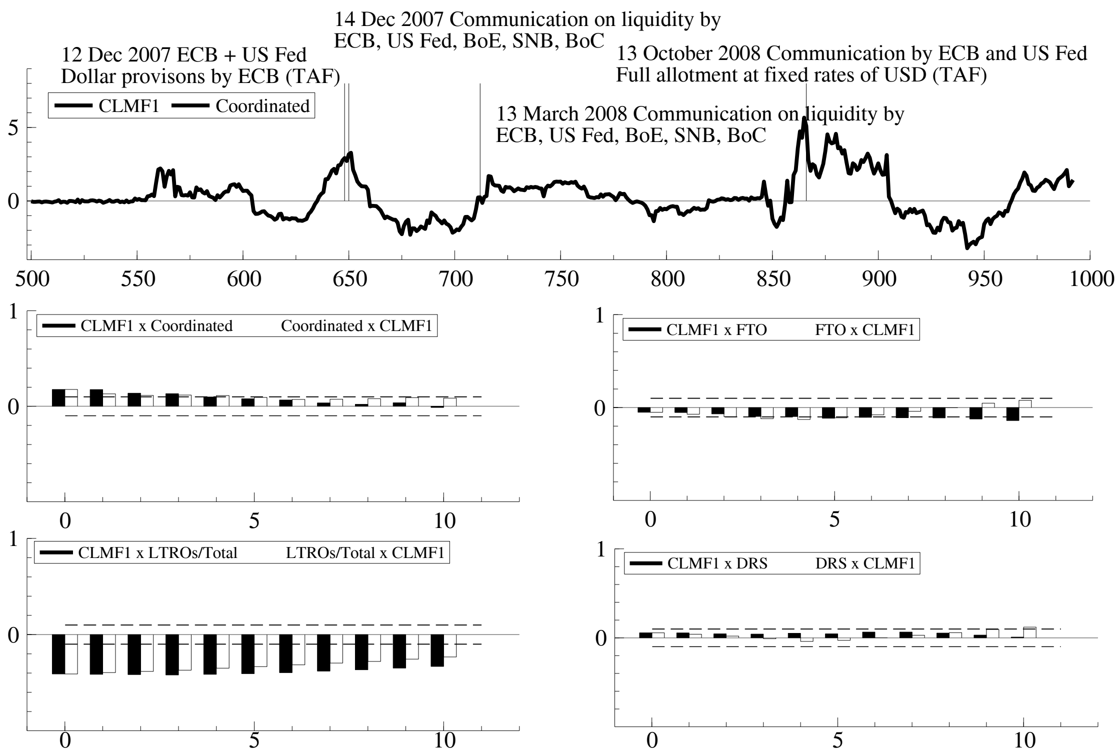

Figure 4: First common long-memory factor (CLMF1) and main coordinated central bank actions (top plot). Cross correlation functions of CLMF1 with main coordinated central bank actions, fine tuning operations (FTO), long term operations/total operation (LTROs/Total), and frontloading of the fulfilment of the reserve requirements (DRS) (other plots).

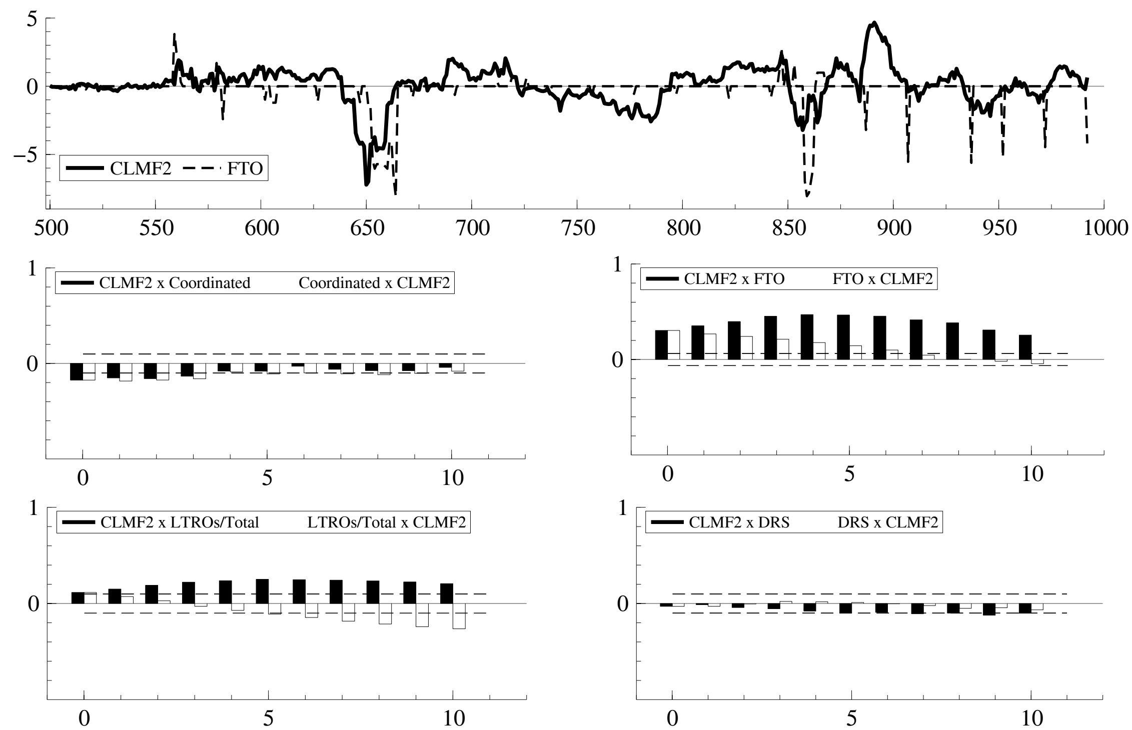

Figure 5: Second common long-memory factor (CLMF2) and fine tuning operations (FTO) (top plot). Cross correlation functions of CLMF1 with main coordinated central bank actions, fine tuning operations (FTO), long term operations/total operation (LTROs/Total), and frontloading of the fulfilment of the reserve requirements (DRS) (other plots).

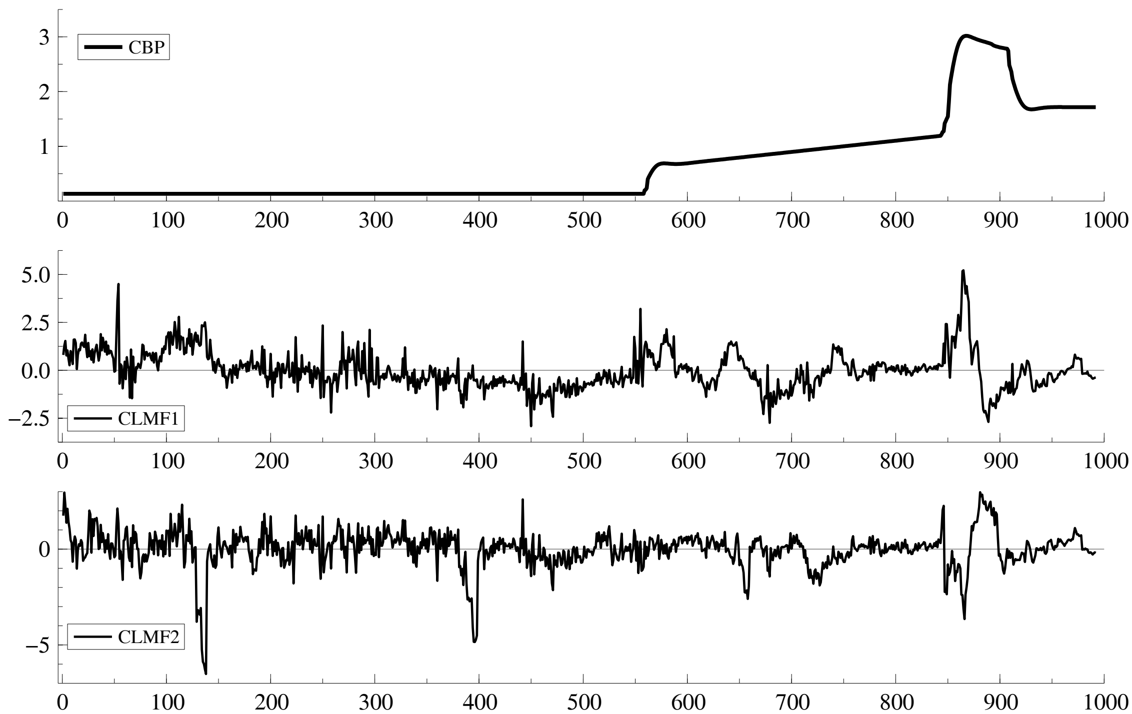

Figure 6: US LIBOR-OIS spreads; common break process (CBP) and common long memory factors (CLMF) from the dummy-spline model (DCSM).

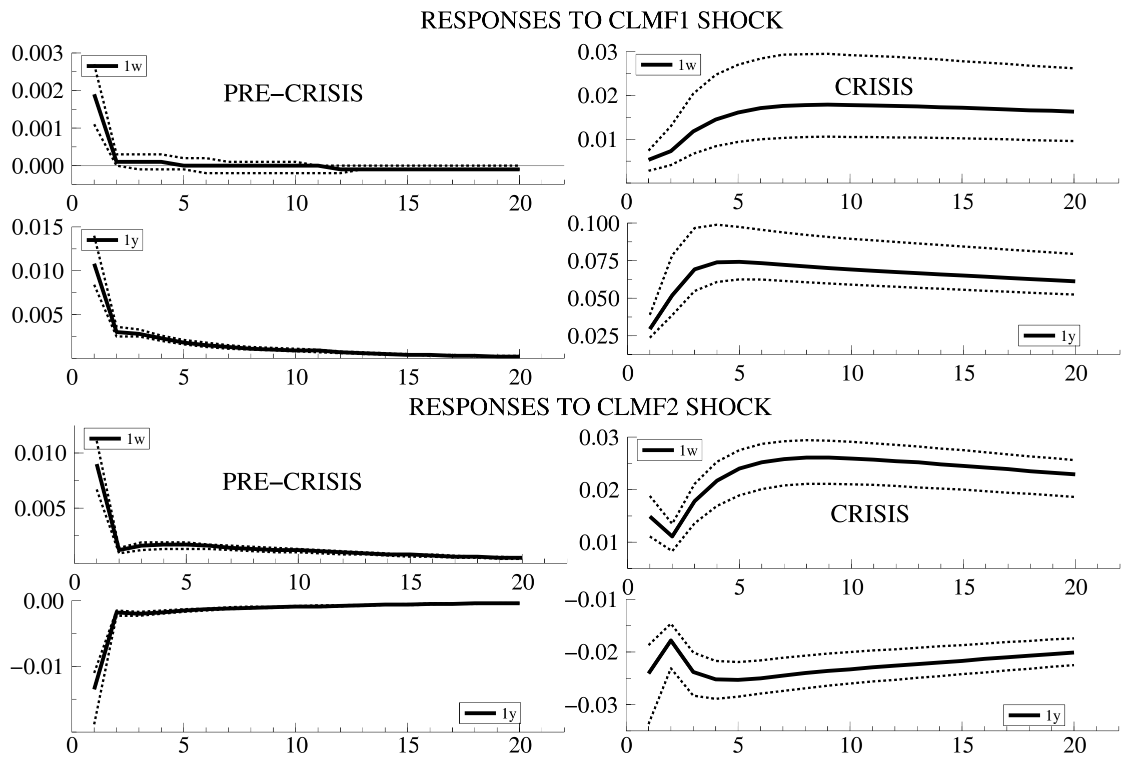

Figure 7: Impulse responses, with 95% confidence interval, to a unitary level factor (CLMF1) shock and slope factor (CLMF2) shock for the pre-crisis (left hand side plots) and crisis (right hand side plots) periods, for the 1-week (1w) and 1-year (1y) maturities.

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