EUROPEAN CENTRAL BANK

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In 2011 all ECB publications feature a motif taken from the €100 banknote.

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Abstract

The recent financial crisis deeply affected the money market yield curve and thus, potentially, the proper functioning of the interest rate channel of monetary policy transmission. Therefore, we analyze the effectiveness of monetary policy in steering euro area money market rates using two measures: first, the predictability of money market rates on the basis of monetary policy expectations, and second the impact of extraordinary central bank measures on money market rates. We find that market expectations about monetary policy are less relevant for money market rates up to 12 months after August 2007 compared to the pre-crisis period. At the same time, our results indicate that the ECB's net increase in outstanding open market operations as of October 2008 accounts for at least a 100 basis point decline in Euribor rates. These findings show that central banks have effective tools at hand to conduct monetary policy in times of crises.

Keywords: Monetary transmission mechanism; Financial Crisis; Monetary policy implementation; European Central Bank; Money market

JEL classification: E43, E52, E58

Non-technical Summary

The financial crisis starting in August 2007 has deeply affected financial markets around the world. In particular, money markets contracted substantially leading to severe disruptions in banks' short-term funding. Interest rates in the unsecured segment of the money market rose to unprecedented levels reflecting banks' re-assessment of borrower's creditworthiness and their willingness and capacity to lend. And, hence, leading to a tightening of credit standards for both businesses and households. These developments have called into question whether monetary policy can effectively steer short term money market rates in such an environment.

In this paper we investigate the effectiveness of the ECB's monetary policy in steering money market rates during the recent financial crisis based on two aspects. First, we explore whether markets' interest rate expectations are adequately reflected in the shape of the money market yield curve. Given the bank-centered structure of the euro area financial system, this relationship is crucial since interest rates, in particular the unsecured money market rates (Euribor), determine short-term bank loans and deposit rates which in turn affect financing conditions for households and businesses. Second, we analyze the extent to which the ECB's crisis related (non-standard) monetary policy measures have been effective in reducing money market rates.

To that aim, we focus on the daily dynamics of the three-month, six-month and twelve-month Euribor during the period March 2004 through June 2009. Along the lines of the expectation hypothesis, we study the interaction of monetary policy and the term structure before and during the recent financial crisis. For the period before August 2007, we find that Euribor rates up to twelve months were significantly in line with market's expectations. According to our results, an expected policy rate change of 25 basis points causes the contemporaneous three-month, six-month, and twelve-month Euribor to rise by 17, 19 and 23 basis points, respectively. After the outbreak of the crisis, however, our results differ from those obtained for the pre-crisis period in two important aspects. First, the yield curve reflects monetary policy intentions less clearly. An anticipated policy rate change of 25 basis points is now accompanied by a contemporaneous increase in three-month, six-month, and twelve-month Euribor rates by roughly 3 basis points. This implies that during the crisis the management of market's expectations became rather difficult. This challenges the proper functioning of the interest rate channel and thus the effectiveness of monetary policy. Second, the Euribor rates became highly persistent. Therefore, a lasting impact of shocks may have impeded the transparency of policy signals and the central bank's impact on money market rates. At the same time, our results suggest that the use of the crisis-related (non-standard) mone-

tary policy measures by the ECB has contributed to a decline in money market rates. In particular, the net increase of outstanding volumes associated with open market operations shows to account for a reduction in Euribor rates by more than 100 basis points.

1 Introduction

The financial crisis starting in August 2007 deeply affected financial markets around the world. In particular, money markets contracted substantially leading to severe disruptions in banks' short-term funding. Unsecured money market rates rose to unprecedented levels reflecting banks' re-assessment of borrower's creditworthiness and their willingness and capacity to lend. And, hence, leading to a tightening of credit standards for both businesses and households, see European Central Bank (2007b). These developments have called into question whether monetary policy can effectively steer short term money market rates in such an environment. This paper investigates the effectiveness of monetary policy with regard to the steering of money market rates during the recent financial crisis using two measures: first, the predictability of money market rates on the basis of monetary policy expectations reflecting the standard channel of monetary policy transmission. And second, the impact of the ECB's crisis-related (non-standard) monetary policy measures on money market rates.

The euro area financial system has a bank-centered structure and as such, unsecured money market rates determine short-term bank loans and deposit rates and thereby financing conditions for households and businesses. The euro interbank offered rate (Euribor), in that respect, is the standard reference rate for the unsecured money market and serves as the benchmark for the pricing of fixed-income securities throughout the economy. Moreover, short-term retail bank interest rates are priced in relation to the Euribor, and mortgage rates are often even indexed to it, see de Bondt et al. (2005), Sorensen and Werner (2006). Therefore, the prevailing Euribor rates appear to significantly influence the effectiveness of monetary policy and the functioning of the transmission mechanism in the euro area.

According to the expectation hypothesis, the current structure of Euribor rates should contain an implicit path of the expected future short term interest rate, i.e. the policy rate set by the central bank, see e.g. Campbell and Shiller (1991), and Rudebusch (1995). This path reflects how interest rates will evolve over time and will change if new information about the economic outlook and monetary policy necessitate a revision of the path. Hence, for an effective monetary policy, it is therefore crucial that interest rate expectations are in line with the central bank policy intentions and are correctly reflected in the shape of the yield curve.

Since the beginning of the recent financial crisis, however, Euribor rates at various horizons rose substantially and remained at elevated levels putting the clarity with which monetary policy intentions are reflected in the shape of the yield curve at risk. To revive conditions in the money market, the ECB, like many other central banks, mainly reacted by increasing significantly the liquidity provision to the banking sector via its open market operations. More precisely, until October 2008 the ECB rearranged its allotment pattern in its main refinancing operations (MROs) and extended its liquidity provision in size and frequency through supplementary longer term refinancing operations (LTROs), albeit overall liquidity provision was kept more or less unchanged. After October 2008, the ECB's balance sheet grew considerably in size due to a number of extraordinary measures including a fixed rate unlimited liquidity provision, a further broadening of refinancing horizons and the establishment of a foreign currency funding facility, notably in U.S. dollars. If these non-standard monetary policy measures were effective, they should lower the tensions in money markets and contribute to a reduction of the marginal cost of funding bank loans, i.e. the Euribor rates.

Following the rationale of the expectation hypothesis, we employ a model of the Euribor to assess (i) its predictability on the basis of market's monetary policy expectations at the three-month, six-month and twelve-month horizon and (ii) the effectiveness of ECB's crisis-related (non-standard) monetary policy measures. Overall, our results indicate that during the recent crisis, monetary policy has been largely effective. Before the financial crisis, Euribor rates up to 12 months were significantly in line with market's expectations. Since the outbreak of the crisis, however, the yield curve reflects monetary policy intentions less clearly. In addition, we find a high persistence in Euribor rates that may have blurred the transparency of monetary policy further. In contrast, the ECB's crisis-related (non-standard) monetary policy measures were highly effective in reducing Euribor rates. In fact, according to our estimates the significant increase in the net volume of outstanding open market operations as of October 2008 caused Euribor rates to decline for more than 100 basis points.

The empirical literature has analyzed the transmission of monetary policy in the euro area through various lenses. Most papers have focused on the effectiveness and relative importance of different transmission channels over the cycle, see e.g. Chatelain et al. (2003), Ehrmann et al. (2003), Peersman and Smets (2003)), whereas other contributions have studied the asymmetric functioning of channels during upswings and downswings, see e.g. Bean et al. (2003), Ehrmann and Worms (2004), Eickmeier et al. (2006). However, the effectiveness of monetary policy during significant crises, and especially during the recent financial crisis has not been sufficiently investigated yet.

Our paper is closely related to earlier work by Bernoth and von Hagen (2004) who analyze the efficiency of the three-month Euribor for the period before 2004. Following Rudebusch (1995), Rudebusch (1998) and Taylor (2001) we use interest rate expectations to assess the predictability of monetary policy from an ex-post perspective. This paper also relates to recent work by the Bank of England (2007), McAndrews et al. (2008), Taylor and Williams (2009), among others, that discusses the risk premia components of elevated unsecured funding market rates after mid 2007. While Taylor and Williams (2009) associate the rise in risk premia predominantly to credit risk factors, the common view acknowledges the existence of both credit and liquidity concerns. However, when measuring these risk components (almost) all empirical studies implicitly assume orthogonality among their risk proxies and decompose the premia into a credit risk and non-credit risk part.[1] We argue that this approach is inaccurate as the risk measures are shown to be highly correlated and a partial regression-type decomposition of risk components yields to biased estimators. Since imperfect multicollinearity tends to produce higher standard errors and thus small *t*-values, this might even explain why e.g. Taylor and Williams (2009) find no significant evidence for liquidity risk in their results.

The remainder of the paper is organized as follows. The next section provides an overview of recent developments in the euro money market and in the Eurosystem's monetary policy regime. In particular, it intends to clarify our definition of an effective monetary policy. Section 3 presents our empirical model and discusses the variables that might determine the dynamic of Euribor rates. In section 4, we present our empirical results. In section 5, we will conclude.

2 Monetary Policy and the Euro Money Market during the Financial Crisis

There are different channels that are viewed to be essential for the effectiveness of monetary policy.[2] A key feature to many of these mechanisms is that the entire expected path of interest rates plays a crucial role in influencing the cost of lending to households and companies. Thus, anticipated monetary policy is priced into the yield curve and affects in turn the level of economic activity and price stability. Therefore, anchoring expectations enhances the effectiveness of monetary policy in facilitating the transmission process, see Woodford (2003). Consequently, the central

[1]The only exception, to our knowledge, is Schwarz (2010) who uses the high frequency data from the e-MID database to derive two orthogonal risk measures. However, this approach implicitly assumes that the risk premia in Euribor rates may be completely assigned to liquidity and credit risk. However, it does not control for volatility effects of future expected overnight rates as well as market liquidity.

[2]For a detailed discussion of these transmission channels see e.g. Mishkin (1995) and Bean et al. (2003). Boivin et al. (2010) review the core channels of policy transmission and provide new insights on how the transmission mechanism might have evolved in recent decades.

bank's degree of predictability of its actions is important for economic agents.

In the euro area, the overnight indexed swap (OIS) is the main instrument used by market participants to take speculative positions on expected central bank actions. In general, European money market rates followed expected short term rates very closely. In fact, in an environment with sufficient liquidity and no market dislocations the interest rate of term bank deposits ought to bear a close relationship with the expectation of the compounded overnight rates over the same horizon, as implied by the expectation hypothesis. For instance, the three-month (3M) euro interbank offered rate (Euribor) has evolved in a close range to the respective 3M European OIS with an average spread of around 8 basis points in the period before August 2007, see Figure A.1.[3] Since the OIS is tied to the European overnight rate (Eonia), this spread stems from a premium that banks pay when they borrow funds for a pre-determined period relative to the expected cost that arises from repeatedly rolling over funding in the overnight market.[4]

In mid 2007 tensions surrounding assets backed by U.S. sub-prime mortgages started to spill over into money markets around the world, leading to shortages of liquidity in money markets. In the euro area, this resulted in an increased demand for liquidity. Combined with heightened uncertainty, it caused (longer-term) money market rates in the unsecured segment increasingly to dry up. In particular, the spread between the Euribor and the OIS rates at all maturities widened significantly suggesting that money market rates along the short end of the yield curve were diverging from their risk free counterparts, see Figure A.1. In order to re-stabilize conditions in the money market, the European Central Bank (ECB) responded to the increased liquidity demand by changing its allotment pattern in its main refinancing operations (MROs) and extending its liquidity provision in size and frequency through supplementary longer term refinancing operations (LTROs). More specifically, the ECB started to allot significant excess liquidity at the beginning of the maintenance period which was then gradually reabsorbed over the remaining weeks of the period by reducing the allotment above the benchmark. This allowed counterparties to meet their

[3]Since money market transactions are carried out on a bilateral basis, they are notoriously hard to obtain. Therefore, established reference rates such as the Euribor serve as the best (available) proxy for actual transactions in the unsecured segment of the money market. See also www.euribor.org for further details. Alternatively, one may use the Italian electronic trading platform e-Mid that accounts for 17 % of all transactions in the shortest-maturity segment of the unsecured European money market. However, since trades are executed in full transparency this platform will rather be used by "good" banks. Thus, data collected from e-Mid should not vary much, in particular in times of crises, from the Euribor rates which themselves are based on a panel of prime banks with the highest credit standards in the euro area. Please refer to Angelini et al. (2009) for an illustration of both data sources.

[4]More explicitly, the two arbitrage legs are: make a loan of € X for (say) three months and then fund the loan by borrowing € X each day in the Eonia market and, finally, hedge the interest rate risk by purchasing an OIS contract, see Gorton and Metrick (2009).

strong preferences of ”frontloading” liquidity at an early stage in the maintenance period. On average, banks still continued to have a liquidity surplus close to zero at the end of each period as before August 2007, see e.g. European Central Bank (2010). Additionally, to address the increased liquidity demand in foreign currency the ECB established a dollar liquidity providing term auction facility (TAF) through a swap with the US Federal Reserve Bank (Fed).

During the second half of 2008, when Lehman Brothers filed for bankruptcy, banks became even more reluctant to engage in interbank money market trading and correspondingly relied upon the use of ECB's refinancing operations, see e.g. Cassola et al. (2009). The tensions in the euro area money market intensified and Euribor rates diverged even further from their OIS counterparts, see Figure A.1. On October 15, 2008 the ECB responded to the exacerbated crisis by a number of extraordinary measures. More specifically, the ECB switched from the variable rate tender format to a fixed rate full allotment policy in order to satisfy the full liquidity demand of the banking sector. Furthermore, the liquidity provision was extended to refinancing operations with six and twelve months of maturity. This increase in the net volume of outstanding open market operations caused ECB's balance sheet to grow substantially, see Figure A.3. The ECB took more explicit steps to lower the cost of unsecured term borrowing and reduced its policy rates by 325 basis points from 4.25% in October 2008 to 1.00% in May 2009. The provision of liquidity at the policy rate and the commitment to continue these non-standard monetary policy measures for a clearly defined period could be interpreted as strong signals to keep rates low as long as needed.[5]

3 Transmission Mechanism of Monetary Policy

3.1 Modelling the Euribor Dynamics

The (weak) form of the expectation hypothesis of the term structure states, from a theoretical perspective, the equality between current longer-term rates and the average expected overnight rate plus a constant maturity specific risk premium, see e.g. Litterman et al. (1991) and Hamilton and Kim (2002).[6] We use this rationale to apply the following model in order to study the dynamics of the Euribor rate (R):

[5] In fact, once policy rates approach levels closer to zero these measures are crucial in shaping the market's expectations about the future monetary policy stance, see e.g. Mishkin (2007).

[6] We consider the weak form of the expectation hypothesis to be the relevant form. The strong view without a premia conflicts with the fact that yield curves normally slope up which would imply that short-term rates are expected to trend upwards indefinitely.

$$\Delta R_t(k) = \alpha(\frac{1}{k}\sum_{j=0}^{k-1} E_t \Delta r_{t+1+j}) + \beta' \Phi_t(k) + \gamma' CB_t + \delta' X_t + \sum_{j=1}^{5} \varphi_j \Delta R_{t-j}(k) + \epsilon_t \quad (1)$$

where Δ denotes the first-difference operator. Our model is expressed in first differences in order to avoid potential issues of non-stationarity that we discuss in the Appendix. α captures the relationship between the current longer-term rate of duration k and the average expected overnight rate over the same horizon, $\frac{1}{k}\sum_{j=0}^{k-1} E_t \Delta r_{t+1+j}$.[7] The expectation hypothesis requires a theoretical one-to-one relationship for it to hold, i. e. $\alpha = 1$. We do not, however, seek to perform a restricted model where we impose the expectation hypothesis on our estimation. In fact, in order to investigate whether the link between Euribor rates and market's monetary policy expectations has changed during the crisis, we need to estimate α. In general, a coefficient estimate of (statistically) less than one need not to point to a failure of the hypothesis, see Kuttner (2001). He argues that changes in current longer-term rates on the day of a policy rate change announcement reflect changes in the average expected overnight rates over the duration of the contract. Therefore, the impact of a one-day surprise should be less than one-for-one, see Demiralp (2008) for empirical evidence on the 3M Treasury Bill rate. Furthermore, Demiralp and Jorda (2004) show that many one-day policy steps have to do with the timing of the action rather than with their ultimate size.

In normal times, the common approach in the expectation hypothesis literature is to treat the (risk) premium as a time-invariant term that is only of negligible amount. Hence, in a first-difference representation, it is then assumed to be zero. In a financial crisis, as recently witnessed, the premium may not only be significant in size but may also change substantially from one day to another. To avoid the problem of omitted variable bias, we have therefore included a vector, Φ, that comprises the various dimensions of risk: (i) (funding and market) liquidity risk, (ii) counterparty risk and (iii) market risk.[8] CB is a vector of measures related to ECB's crisis-related (non-standard) monetary policy measures undertaken to mitigate the strains in the money market. We use this variable to investigate whether these measures managed to decrease Euribor rates.[9]

[7] For long-term interest rates beyond the 10 year horizon, the Jensen's inequality term arises because a log of an expectation does not equal the expectation of a log. At our maturities, however, this term is rather negligible and hence needs no consideration in our analysis.

[8] Among the bank-specific variables, it is useful to distinguish between the compensation for the risk of default and a premium related to the demand for funds, which depends upon the ease of funding by borrowing (funding liquidity). Market-wide conditions include the uncertainty about the path of expected overnight rates, which is reflected in a term premium, the ease of trading (market liquidity), and factors related to the fixing process and the microstructure of the market.

[9] Note, however, that this procedure is not sufficient to identify the causal effects of central bank actions.

X reflects a vector of dummies controlling for calendar effects in the data.[10] Along the lines of Hassler and Nautz (2008) and Busch and Nautz (2010), controllability of money market rates requires sufficiently low persistence in longer-term money market rates. If money market rates are too persistent the lasting impact of shocks can impede the transparency of policy signals and the central bank's monetary policy influence on money market rates along the yield curve. Hence, we measure the persistence in Euribor rates by $\sum_{j=1}^{5} \varphi_j$.[11]

3.2 Variables

3.2.1 Market's Expectation

In the euro area, the OIS market constitutes the most important derivative market. In general, it serves as the main platform to manage short-term interest risk exposures and covers roughly 40% of the overall OTC derivatives market, see e.g. European Central Bank (2007a). There are two parties that are involved in a OIS contract out of which one commits to pay a fixed rate (swap rate) and one paying a variable rate (average Eonia over the maturity of the swap). The $OIS_t(k)$ rate can be interpreted as the average short-term rate that the market expects to prevail for the next k days. Hence, OIS rates are a natural proxy for the average expected overnight rate, such that $\Delta OIS_t(k) \approx \frac{1}{k} \sum_{j=0}^{k-1} E_t \Delta r_{t+1+j}$.[12] Changes in the OIS rate would, thus, suggest revisions in expectations of future overnight rates over the course of the correspondingly dated Euribor rate. In other terms, for an effective monetary policy, α should be significant and positively signed in order for OIS rates to help to explain Euribor rates.[13]

3.2.2 Risk Measures

During the recent financial crisis, there have been different forms of risk at play: *liquidity risk* (Eisenschmidt and Tapking (2009)), *credit risk* (Taylor and Williams (2009)), and the *combination* of liquidity and credit risk (Brunnermeier (2009), Brunnermeier and Pedersen (2009), Christensen et al. (2009), Schwarz (2010), McAndrews et al. (2008)). In the attempt to derive an accurate measure for each of the additive forms of risk, the following two approaches have been suggested.

Rather, it measures interest rate movements immediately after central bank actions.

[10] For instance, liquidity pressures in money markets may arise due to end-of-year window dressing of balance sheets by financial institutions.

[11] Since we use daily observations, a lag order of five days seems reasonable. This is also suggested by the AIC information criteria.

[12] Refer to Carpenter and Demiralp (2009) for a similar approach applied to the U.S. market.

[13] Since March 2008, the announcement of OIS rates has changed from 4:30 p. m. CET to 11 a. m. CET. In line with the fixing of the Euribor, the definition of $\Delta OIS_t(k)$ is adjusted accordingly.

On the one hand, one may assume that the risk component in Euribor rates are fully explained by (funding) liquidity and by a credit part. But this approach bears the problem associated with omitted variable bias since volatility effects of future expected overnight rates as well as market liquidity, in general, are completely ignored. To circumvent this, one may use on the other hand a two step approach following the logic of the partitioned regression analysis. This would enable a decomposition of risk premia into e.g. a credit and non-credit part. Such an approach implicitly assumes orthogonality between the risk factors. But as Brunnermeier and Pedersen (2009) and Brunnermeier (2009) argue, these risk factors mutually affect and even reinforce each other. Therefore, (at least) one of the estimated coefficients of the risk variables will be biased. This is a consequence of misleadingly allocating the joint variation of the risk measures to one of the decomposed risk elements. We will therefore suggest the following variables in order to avoid these issues and capture the major risk parts in Euribor rates.

The (five-year, BBB rated) yield spread between *financial corporate and government bonds* will serve as our credit risk proxy. Bonds, in general, are debt securities generating identical cash flows in all states of the world. Corporate bonds are issued by companies as a way of raising money to invest in their business. They have nominal value which is the amount that will be returned to the investor on a stated future date (the redemption date). This pays a (usually) fixed interest rate each year. Government bonds are backed by the full faith and credit of the fiscal authority. Hence, a financial corporate bond normally bears a default risk and hence carries higher interest rates than a government bond. The spread is therefore a natural proxy for credit risk.[14] Higher values of this variable should lead to an increase in Euribor rates.

As our liquidity risk proxy, we will use the spread between the rate for fully collateralized loans (Eurepo GC) in the money market and the risk-free OIS rate. Repurchase agreements between banks backed by government (guaranteed) bonds and bills are a form of secured lending.[15] In contrast to a swap agreement, in a collateralized transaction liquidity changes hands and therefore the lending party requires a liquidity premium that depends upon the duration of the loan. Thus, the *Eurepo-OIS spread*, or the expectations-adjusted Eurepo rate, can be considered as a reliable liquidity risk proxy.[16] And a rise in the spread should put an upward pressure of Euribor rates.

[14] We may use CDS spreads instead as commonly applied. However, it is not clear whether CDS spreads reflect a faire probability of default. For instance, in 2008 hedge funds in Iceland engaged in CDS contracts to speculated on sovereign and corporate default.

[15] Loans at the Eurepo have strict requirements on the type and quality of the collateral. For a list of eligible collateral, see http://www.eurepo.org

[16] We are aware of the fact that concerns about the delivery or return of the collateral may be priced in Eurepo rates. Furthermore, in a strict sense OIS rates are not risk-free as one of the involved parties may

We use the Chicago Board Options Exchange Volatility Index (*VIX*) in order to account for implied future volatility in the stock market. VIX is a weighted average of implied volatilities of a wide range of Standard and Poor's 500 index (put and call) options. It reflects market's expectation of volatility over the next 30 days period and is often referred to as the "investor fear gauge". In addition, since the VIX captures (expected) adverse price changes of market valued assets, it thereby reflects (at least indirectly) changes in market liquidity as well. As presented in Brunnermeier and Pedersen (2009), when funding liquidity dries up in an environment of market stress, margins will be recalled and that in turn will affect asset prices as they will drop due to fire sales. As a result, market liquidity will dry up too. High values of VIX point to a greater uncertainty in the stock market that should put an upward pressure on Euribor rates.

3.2.3 Central Bank Measures

As part of its weekly financial statement, the ECB announces its net lending associated with its monetary policy operations to credit institutions. The *outstanding volumes* of both the MROs and all LTROs are therefore a natural variable representing the size of the ECB's liquidity provision. While the ECB's open market operations do not have a direct impact on money and credit aggregates, they may have affected monetary developments indirectly through their impact on short-term money market rates and the pass-through of these rates to bank lending and deposit rates. Such indirect effects, which work through the opportunity cost of holding money and the cost of external financing, reflect demand by households and firms for money and bank credit. In general, more liquidity supply should affect interest rates.

In pre-crisis times, MROs should not affect Euribor rates since the ECB's liquidity management is performed so as to allow banks to fulfill their reserve requirements during the reserve maintenance period which is usually 4 to 5 weeks. LTROs should have no impact on the Euribor before August 2007 whatsoever since these operations were conducted as variable rate tender *without* a minimum bid rate. Hence, the ECB acted as a price taker and pre-announced the liquidity amount that it deemed appropriate to allot. Alternatively, one may argue that MROs and LTROs aimed to satisfy neutral conditions before August 2007 while after mid 2007, MROs and LTROs became a policy instrument to steer interest rates.

In any case, if the wide range of crisis-related (non-standard) monetary policy measures un-

default and the remaining party is subject to the differential in the fixed and overnight components of the swap.

dertaken by the ECB as of August 2007 were effective in lowering the strains in the money market, we would expect a reduction in Euribor rates through the increase in net volume of outstanding open market operations. To examine the effect of the *US dollar liquidity provision* through a swap with the U.S. Fed, we define a dummy variable as follows.[17] The indicator denoted by $D_{TAF} = 1$ on a day of any term auction facility (TAF) operation and zero on other days.

Furthermore, we control for the announcement effect of each operation since news releases can change prices themselves. Regular MROs and LTROs are announced in an annual indicative calendar three months before the year for which it is valid. Therefore, we will only consider announcement effects related to supplementary refinancing operations (sLTRO) during the crisis period. Hence, $D^{an}_{sLTRO} = 1$ for all days on which a sLTRO was announced and zero otherwise. In the same vein, we define $D^{an}_{TAF} = 1$ for all announcement days of TAF operations and zero otherwise.[18] If the undertaken measures have been effective in reducing elevated money market rates, the expected signs of the coefficients are negative.

3.3 Data

We use daily data from March 2004 to June 2009 to estimate equation (1) for the 3M, 6M and 12M Euribor. Prior to March 2004, banks had difficulties to assess the ECB's allotment policy. Banks had to carry out complex still not accurate calculations in order to determine ECB's benchmark allotment. This uncertainty about ECB's behavior caused uncertainty regarding money market rates and thus the pricing of risk premia along the yield curve, see e.g. Jardet and Fol (2007). From March 2004 onwards, the ECB facilitated counterparties' anticipation of its liquidity allotment in the MROs by publishing its calculation of the benchmark allotment.[19] To ensure that our dynamics in Euribor rates are not affected by bank's uncertainty about ECB's allotment stance, we will start

[17]Taylor and Williams (2009) and McAndrews et al. (2008) apply a similar technique for the federal funds and U.S. Libor market. Note that for this analysis, modeling our equation of the Euribor in first differences is the most appropriate approach. A level representation would implicitly assume that the (liquidity) risk premium that might fall on a day of ECB's operation will revert to the previous level immediately after the operation. However, if the liquidity premium remains at the lower level over many days after an operation, the estimated coefficient of the event cannot be interpreted as a central bank effect and it would likely appear insignificant.

[18]On February 1, 2008 the ECB announced that it would not participate in the February US dollar liquidity providing operations. Therefore, we define $D^{an}_{TAF} = -1$ for that special date since this announcement might have reduced the anticipated supply of liquidity in the TAFs and thereby might have put an upward pressure on money market rates.

[19]The benchmark allotment is the allotment normally required to establish balanced conditions in the short-term money market, given the ECB's complete liquidity forecast. Balanced liquidity conditions should normally result in an overnight rate close to the policy rate. The benchmark allotment constitutes a baseline for the ECB when making its actual allotment decision, see European Central Bank (2004).

our sample with the first maintenance period after ECB's operational framework revision on 10 March, 2004.

In order to account for the changes in risk premia and in the demand and supply of liquidity, we allow money market rates to respond differently to its determinants after August 2007. Therefore, we explore the Euribor dynamics for the crisis and pre-crisis sample separately. In fact, splitting our sample on August 9, 2007 is also implied by structural breakpoint tests, see Section D in the Appendix. This leaves us with 802 and 424 observation for the period 10 March 2004 - 8 August 2007 (pre-crisis) and 9 August 2007 - 30 June 2009 (crisis), respectively. Table 1 summarizes the estimation results for our model of the 3M, 6M and 12M Euribor.

4 The Effectiveness of Monetary Policy: Empirical Results

4.1 Before the Crisis

For all our maturities, α is plausibly signed and highly significant. This suggests that, all other things being equal, an expected change in the policy rate produces a shift in the yield curve, at least at the short end. If markets expect short-term rates to rise in the near future, there is a proportional increase in Euribor rates. According to our results, an expected policy rate change of 25 basis points will cause the 3M, 6M and 12M Euribor rate to rise immediately by 17, 19 and 23 basis points, respectively.[20] This result strongly supports the relevance of market's monetary policy expectations for longer-term money market rates.

Our results also show that risk premia determine euro unsecured money market rates in a significant way. Both credit risk and liquidity risk considerations increase with maturity. In absolute terms, the major component of the risk premia in Euribor rates can be assigned to (funding) liquidity risk. Changes in the expectation-adjusted GC Eurepo rate by 10 basis points will be followed by upward movements in the 3M, 6M and 12M Euribor rate by roughly 6, 8, and 9 basis points, respectively.[21]

[20] Note that we relaxed the the assumption of the constant premia. Hence, the expectation hypothesis no longer attributes *all* changes in the yield curve solely to changes in expected short rates.

[21] The Wald test of parameter equality (not reported) cannot reject the null hypothesis $H_0 : \alpha = \beta_2$. Since $\Delta Eurepo = \Delta OIS + \Delta(Eurepo - OIS)$, equation (1) is a re-parametrization of the representation which includes both the relationships between market expectations and Euribor rates and the secured vs. unsecured money market rates, i. e. ΔOIS and $\Delta Eurepo$. This close connection has been reported by Taylor and Williams (2009) for U.S. equivalents.

Table 1: The model for the Euribor

$$\Delta R_t(k) = \alpha(\frac{1}{k}\sum_{j=0}^{k-1} E_t \Delta r_{t+1+j}) + \beta' \Phi_t(k) + \gamma' CB_t + \delta' X_t + \sum_{j=1}^{5} \varphi_j \Delta R_{t-j}(k) + \epsilon_t$$

Variable	Coefficient	3m Euribor		6m Euribor		12m Euribor	
		pre-crisis	crisis	pre-crisis	crisis	pre-crisis	crisis
Δ *Market's Expectations*	α	0.620^{***} (10.44)	0.102^{**} (2.50)	0.775^{***} (30.16)	0.115^{***} (3.04)	0.913^{***} (81.85)	0.163^{***} (5.40)
Δ *Corporate vs. Government Bond spread* (BBB rated)	β_1	0.028 (1.39)	0.007 (1.44)	0.035^{*} (1.87)	0.009 (1.49)	0.046^{**} (2.02)	0.011 (1.51)
Δ *Eurepo-OIS spread*	β_2	0.599^{***} (8.38)	0.144^{***} (3.82)	0.767^{***} (27.05)	0.176^{**} (2.58)	0.923^{***} (83.77)	0.218^{***} (5.83)
Δ *VIX*	β_3	0.001^{**} (2.08)	0.001 (1.33)	−0.001 (0.98)	−0.001 (0.55)	−0.001 (0.91)	0.001 (0.62)
MROs (outstanding vol.)	γ_1	0.001 (0.60)	-0.016^{**} (2.41)	0.001 (0.53)	-0.014^{**} (2.20)	0.001 (0.28)	-0.016^{***} (2.62)
LTROs (outstanding vol.)	γ_2	0.001 (1.08)	-0.018^{**} (2.34)	0.001 (1.30)	-0.015^{*} (1.67)	0.001 (0.75)	-0.014^{*} (1.67)
TAF (dummy)	γ_3		0.002 (0.89)		0.001 (0.18)		-0.003^{**} (1.96)
Ann. of 3M sLTROs	γ_4		-0.005^{*} (1.82)		-0.007^{*} (1.03)		−0.007 (1.33)
Ann. of 6M sLTROs	γ_5		0.005 (1.03)		0.005 (1.29)		0.004 (1.04)
Ann. of 12M sLTROs	γ_6		0.001 (0.96)		0.003 (1.64)		-0.004^{**} (2.06)
Ann. of TAFs	γ_7		−0.002 (1.07)		−0.001 (0.37)		−0.001 (0.30)
Persistence	$\sum_{j=1}^{5} \varphi_j$	0.227^{***} (3.89)	0.692^{***} (11.99)	0.064^{*} (1.83)	0.629^{***} (8.52)	0.011 (0.53)	0.479^{***} (6.31)
R^2		0.62	0.69	0.79	0.66	0.93	0.58
Obs.		802	424	802	424	802	424

Notes: The table refers to Equation (1). ***,**,* indicate significance at the 1%, 5%, 10% level. Absolute t-statistics are computed according to Newey and West (1987). The term auction facility (TAF) is included as a dummy variable that equals 1 on a day with any TAF operation and zero on other days. The dummy variables to account for announcement effects are defined analogously. The pre-crisis sample runs from 10 March 2004 to 8 August 2007, and the crisis sample ends in 30 June 2009.

Given the high correlation (0.47) between the yield spread of corporate and government bonds and the VIX, our respective data set provides little information about what happens to Euribor rates when credit risk concerns are low but VIX is high, or vice versa. In fact, the weak power to reject the null of non-significance is very likely to be due to the issue associated with imperfect multicollinearity: high correlation between the regressors leads to large variance of the OLS estimator that in turn causes small *t*-values.[22] The *F*-tests of joint significance (see B.1 in the Appendix) show clearly that there is a significant joint impact stemming from these risk measures. This result supports our approach to include a set of risk variables into our estimation that otherwise would suffer from the problem of omitted variable bias. However, our OLS estimators remain unbiased and the overall fit is not affected.

In line with our hypotheses, there is no particular effect from the Eurosystem's open market operations on money markets during tranquil times. This is intuitive since the liquidity amount to be allotted in ECB's LTROs has always been pre-announced. The low persistence in Euribor rates before mid 2007 highlight the ECB's stable control over longer-term money market rates.

4.2 During the Crisis

For the period after the onset of the financial crisis, we present our empirical results of the Euribor equation in the second column of each maturity horizon in Table 1. At first sight, the results differ from those obtained for the pre-crisis period in two important aspects.

First, according to the large and significant estimates of φ_j Euribor rates became severely persistent. In fact, we observe a threefold increase in persistence for the 3M rates, a 10-fold increase for 6M rates, and a 45-fold rise in 12M rates. Second, the predictability of Euribor rates on the basis of market expectations of future overnight rates has diminished quite significantly. An anticipated policy rate change of 25 basis points is now accompanied by a contemporaneous increase of the 3M, 6M, and 12M Euribor rate by roughly 3 basis points. In addition to these short-term effects, our estimates also suggest a change in the long-run dynamics during the period after mid 2007. For instance, while the long-term effects of market's expectations on the 3M, 6M, and 12M Euribor before the crisis amounted to 0.80, 0.83, and 0.92, respectively, the coefficients were

[22] To see this effect we consider the variance of $\hat{\beta}_1$ in a multiple regression setup with two regressors (X_1 and X_2) for the simple case of a homoskedastic error. In large samples, the sampling distribution of $\hat{\beta}_1$ is $N(\beta_1, \sigma^2_{\hat{\beta}_1})$, where $\sigma^2_{\hat{\beta}_1} = \frac{1}{n}\left(\frac{1}{1-\rho^2_{X_1,X_2}}\right)\frac{\sigma^2_u}{\sigma^2_{X_1}}$. The variance of $\hat{\beta}_1$ is inversely proportional to $1-\rho^2_{X_1,X_2}$, where $\rho^2_{X_1,X_2}$ is the correlation between X_1 and X_2.

roughly 0.33, 0.30, and 0.31, respectively, after August 2007.[23] Hence, the higher persistence and the related more lasting impact of shocks may have contributed to the increase in the marginal cost of funding bank loans in the interbank market. Moreover, this greater persistency in money market rates also implies that it is more difficult for monetary policy signals to be transmitted through money market rates along the yield curve via conventional channels of monetary policy.

Following Table B.1, during the crisis liquidity risk and credit risk concerns have become severely correlated. This stylized fact is consistent with the general view that liquidity and credit risk cannot be separated as both measures mutually affect each other, see e.g. Sarkar (2009) and the references therein. Hence, it remains difficult to interpret the coefficients $\widehat{\beta}_1$, $\widehat{\beta}_2$, and $\widehat{\beta}_3$. The F-statistic, however, implies that there is a significant join impact stemming from the risk measures.

Table 2: Wald tests on parameter equality

$\mathcal{H}_0 : \mathcal{D} = 0$		3m Euribor	6m Euribor	12m Euribor
Δ *Market's Expectations*				
$\mathcal{D} : \alpha^{precrisis} - \alpha^{crisis}$	=	0.518 (0.0000)	0.660 (0.0000)	0.750 (0.0000)
CB measures (outstanding vol.)				
$\mathcal{D} : \gamma_1^{precrisis} - \gamma_1^{crisis}$	=	0.017 (0.0068)	0.015 (0.0185)	0.017 (0.0070)
$\mathcal{D} : \gamma_2^{precrisis} - \gamma_2^{crisis}$	=	0.019 (0.0137)	0.016 (0.0710)	0.015 (0.0803)
$\mathcal{D} : (\gamma_1 + \gamma_2)^{precrisis} - (\gamma_1 + \gamma_2)^{crisis}$	=	0.018 (0.0044)	0.015 (0.0151)	0.016 (0.0096)
Persistence				
$\mathcal{D} : \sum_{j=1}^{5} \varphi_j^{precrisis} - \sum_{j=1}^{5} \varphi_j^{crisis}$	=	−0.465 (0.0000)	−0.565 (0.0000)	−0.468 (0.0000)

Notes: Wald statistics refer to the estimated coefficients in Table1. p-values are presented in parentheses.

Probably reflecting the decreasing ability to manage expectations properly, the estimated representation of the Euribor rates indicates a growing importance of the refinancing volumes allotted in the MROs and LTROs. However, we cannot reject the null hypothesis $H_0 : \gamma_1 = \gamma_2$, see Table 2. Hence, the ECB's liquidity provision may only lower Euribor rates when the net volume of outstanding open market operations changes significantly. Recall that until October 2008, even though the ECB rearranged the pattern and shares of MROs and LTROs in the total volume of

[23] The fact that there is a difference between short-term and long-term coefficients is a result of our specification which includes lagged endogenous variables. To illustrate this, let us consider our model in the following general representation: $y_t = c + \sum_{j=1}^{p} \varphi_j y_{t-j} + \theta' X_t + \epsilon_t$, where ϵ_t is an *iid* shock and X_t a vector of exogenous variables. Supposing that $E(y_t)$ and $E(X_t)$ are constant over time, our model can be rewritten as $E(y_t) = \frac{c}{1-\sum_{j=1}^{p} \varphi_j} + \left(\frac{\theta}{1-\sum_{j=1}^{p} \varphi_j}\right)' E(X_t)$ where the long-run relationship between y and X is thus given by $\frac{\theta}{1-\sum_{j=1}^{p} \varphi_j}$.

outstanding open market operations, the net volume has *not* increased, on average, compared to the pre-crisis period, remaining at around € 450 billion. In the sum, the effects from the changes in the shares of MROs and LTROs (from 70% and 30% before 2007 to roughly 30% and 70% after 2007) may not have brought down Euribor rates. However, one may also argue that the rearrangement of the liquidity provision has established (some degree of) confidence that might have prevented Euribor rates from rising further, see e.g. Mishkin (2009). After October 2008, however, when the ECB introduced a fixed rate full allotment policy, i. e. every bank obtained what it demanded, the volume of outstanding refinancing operations increased significantly and peaked even to levels of around € 890 billion, see Figure A.3. In total, the aggregate amount of outstanding open market operation rose, on average, by more than 60% during our sample period. According to our estimates of $\widehat{\gamma}_1$ and $\widehat{\gamma}_2$, this implies a reduction of Euribor rates by more than 100 basis points. This finding provides strong evidence for the effectiveness of monetary policy in alleviating the strains in money market rates along the short-end of the yield curve. In addition, we find that the announcement of supplementary LTROs with 3M maturity had a plausible sign. However, the effect appears to be weakly significant only for the 3M and 6M horizon. Note that the announcement of one year LTROs diminished 12M Euribor rates further. While the introduction of TAF operations has helped to reduce 12M Euribor rates, Table 1 shows that the U.S. dollar provision had no mitigating effect at the 3M and 6M horizon, neither the actual operations nor the announcements.

5 Conclusion

The ECB implements its monetary policy by steering the very short-term money market rate, i. e. the Eonia. In normal times, it is thereby able to influence the term money market rate, i. e. Euribor, that in turn determine short-term interest rates for retail bank loan and deposit rates. Since the outbreak of the financial crisis in August 2007, however, euro money market rates have been severely impaired causing Euribor rates to rise to unprecedented levels. In this paper we have analyzed whether these developments have compromised the effectiveness of monetary policy in steering money market rates. Towards this aim, we have looked at two criteria. First, how well have monetary policy expectations been reflected in the money market yield curve and second, how has the ECB's crisis related (non-conventional) monetary policy measures affected money market rates of three-month, six-month and twelve-month maturity.

We found that as in the financial crisis money market rates have been heavily impacted by risk concerns, the ability of the central bank to steer money market rates via standard channels of monetary policy transmission was weakened. We show that the reflection of monetary policy expectations in Euribor rates has declined substantially. At the same time, however, our results indicate that the ECB's crisis-related (non-standard) monetary policy measures have proven to be effective in reducing money market rates.

We conclude that part of the loss in the effectiveness of monetary policy during the financial crisis via the traditional interest rate channel was compensated by the effective use of liquidity operations affecting money market rates beyond the daily maturity. In fact, before the crisis monetary policy operations were neutral with respect to the monetary policy stance, i.e. they did not affect money market rates at longer term maturities. During the financial crisis, however, the significant expansion of the central bank balance sheet and the conduct of fixed rate tenders with full allotment have exerted a significant influence on the dynamics of money market rates at three-month, six-month, and twelve-month maturities. In particular, our results indicate that the ECB's net increase in outstanding open market operations as of October 2008 accounts for at least a 100 basis point decline in Euribor rates. Therefore, overall, our results clearly show that central banks indeed have adequate tools at their disposal to conduct effective monetary policy, also in times of crises.

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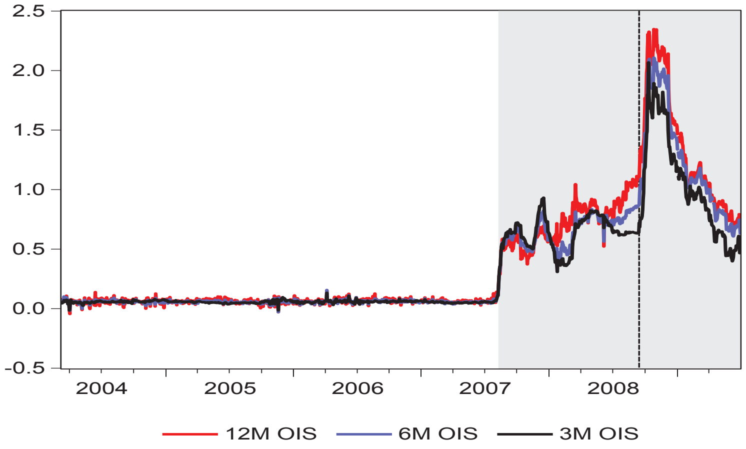
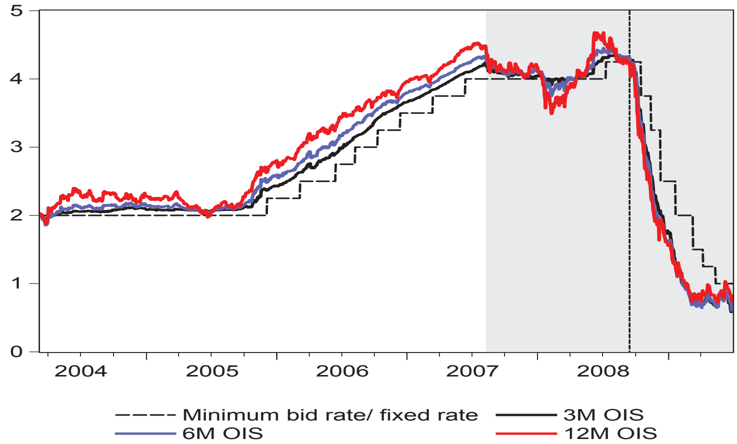
A Figures

Figure A.1: The 3M, 6M, and 12M Euribor-OIS Spread



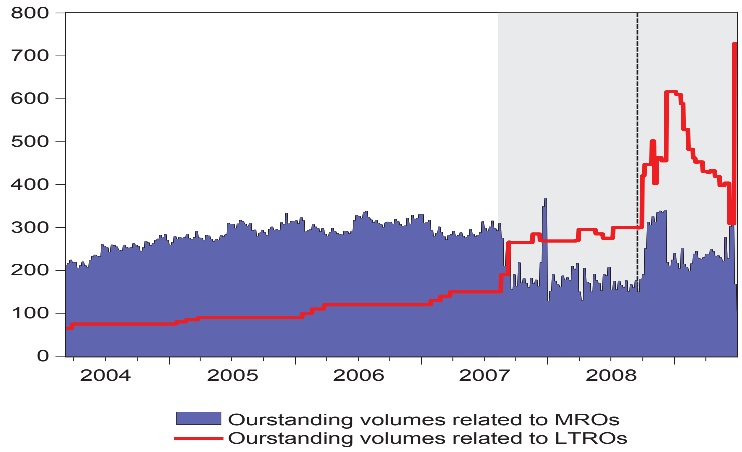
Notes: The shaded area refers to the period after August 9, 2007 and the dashed vertical line refers to the Lehman bankruptcy on September 15, 2008.

Figure A.2: The 3M, 6M, and 12M Euribor and the Minimum Bid Rate and



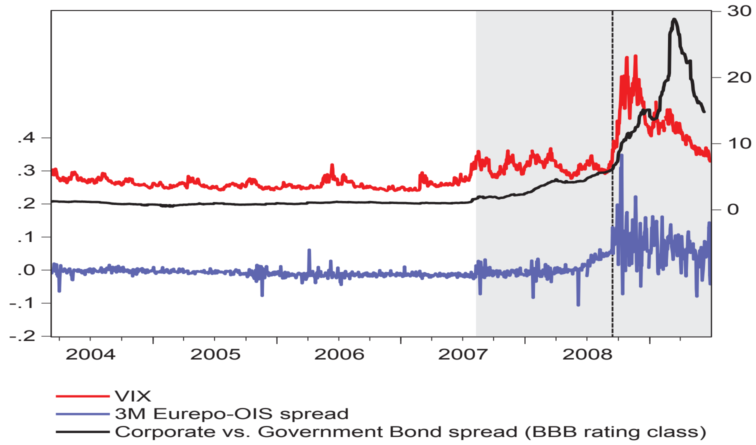
Notes: As of October 15, 2008 the ECB changed the tender mechanism of its MROs from a variable rate tender with a minimum bid rate to a fixed rate full allotment auction format. For further details, please refer to Figure A.1.

Figure A.3: The Outstanding Volumes related to MROs and LTROs (in billion euros)



Notes: Prior to August 2007, the average outstanding volume associated with refinancing operations amounted to € 450 billions. This changed drastically in the period after the Lehman bankruptcy. In the period from mid 2007 until June 2009, the outstanding volume inclined to € 890 billions. For further details, please refer to Figure A.1.

Figure A.4: The 3M Eurepo-OIS Spread, 5Y Bond Yield Spread and VIX



Notes: For details, please refer to Figure A.1

Table A.1: The Euribor dynamics before and after October 2008

$$\Delta R_t(k) = \alpha(\frac{1}{k}\sum_{j=0}^{k-1} E_t \Delta r_{t+1+j}) + \beta' \Phi_t(k) + \gamma' CB_t + \delta' X_t + \sum_{j=1}^{5} \varphi_j \Delta R_{t-j}(k) + \epsilon_t$$

Variable	Coefficient	3m Euribor		6m Euribor		12m Euribor	
		until Oct 2008	after Oct 2008	until Oct 2008	after Oct 2008	until Oct 2008	after Oct 2008
Δ *Market's Expectations*	α	0.112** (2.15)	0.142*** (3.32)	0.161*** (4.49)	0.107*** (4.56)	0.237*** (9.32)	0.112*** (5.83)
Δ *Corporate vs. Government Bond spread* (BBB rated)	β_1	0.041** (2.29)	0.002 (0.33)	0.058*** (3.15)	−0.002 (0.45)	0.075*** (3.07)	−0.001 (0.08)
Δ *Eurepo-OIS spread*	β_2	0.196*** (3.10)	0.131*** (4.17)	0.217*** (4.92)	0.187*** (3.45)	0.260*** (9.36)	0.138*** (4.36)
Δ *VIX*	β_3	0.001 (0.74)	0.001 (1.32)	−0.001 (0.64)	−0.001 (1.53)	−0.001 (0.58)	−0.001 (1.55)
MROs (outstanding vol.)	γ_1	−0.017** (2.13)	−0.017** (1.97)	−0.009** (1.84)	−0.019** (2.32)	−0.008** (1.99)	−0.023*** (2.87)
LTROs (outstanding vol.)	γ_2	−0.024*** (2.70)	−0.016** (2.28)	−0.012** (1.89)	−0.022* (1.87)	−0.007* (1.73)	−0.025** (2.21)
TAF (dummy)	γ_3	−0.002 (0.90)	0.001 (0.19)	−0.001 (0.28)	−0.001 (0.18)	−0.004** (1.08)	−0.002 (0.72)
Ann. of 3M sLTROs	γ_4	−0.002 (0.74)	0.008 (0.69)	−0.006 (1.05)	0.018 (1.52)	−0.006 (1.00)	0.016 (1.33)
Ann. of 6M sLTROs	γ_5	0.013 (1.40)	−0.008 (0.71)	0.004 (0.37)	−0.010 (0.97)	0.003 (0.31)	−0.008 (0.72)
Ann. of 12M sLTROs	γ_6	0.001 (0.58)	0.010 (0.94)	0.002 (0.13)	0.001 (0.32	−0.004 (0.23)	0.001 (0.56
Ann. of TAFs	γ_7	0.003 (0.83)	0.001 (0.31)	0.002 (0.47)	−0.002 (0.58)	0.001 (0.27)	−0.002 (0.64)
Persistence	$\sum_{j=1}^{5} \varphi_j$	0.662*** (6.85)	0.676*** (9.71)	0.516*** (6.59)	0.677*** (8.15)	0.285*** (4.04)	0.638*** (7.57)
R^2		0.58	0.81	0.61	0.74	0.48	0.72
Obs.		274	150	274	150	274	150

Notes: The aim of this table is to show that our results for the period after August 2007 are not driven by the structural change in ECB's tender procedure as of October 2008. The table refers to Equation (1). The first column for each interest rate refers to the period from 9 August 2007 to 14 October 2008, while the second column covers the sample as of October 15 2008 until June 30 2009. For further details, please refer to Table 1

B Correlation Analysis

Table B.1: Correlation Analysis among Risk Measures

	Pre-crisis		Crisis	
	Corporate vs. Government Bond	VIX	Corporate vs. Government Bond	VIX
3-Month Eurepo-OIS	−0.19 (0.00)	0.06 (0.10)	0.52 (0.00)	0.64 (0.00)
6-Month Eurepo-OIS	−0.05 (0.14)	0.04 (0.29)	0.75 (0.00)	0.58 (0.00)
12-Month Eurepo-OIS	−0.07 (0.03)	0.02 (0.58)	0.66 (0.00)	0.56 (0.00)
VIX	0.47 (0.00)	−−	0.61 (0.00)	−−

Notes: The pre-crisis sample runs from 10 March 2004 to 8 August 2007, and the crisis sample ends in 30 June 2009. p-values are presented in parentheses.

Table B.1 presents the results from a Pearson covariance analysis. It shows that the interdependence between the respective risk measures has significantly changed since the start of the financial crisis. The significant interaction among all variables indicates that it is not reasonable to assume orthogonality between liquidity and credit risk measures. Thus, the OLS estimations of β_1, β_2, and β_3 in Equation (1) will be subject to the issues related with imperfect multicollinearity, i.e. large variances and small t-scores. In this case, testing the individual coefficients one at a time leads to unreliable results. In this respect, the F-statistic is a powerful tool to test the joint impact of highly correlated variables.[24] Table B.2 provides these test statistics and shows that our risk variables jointly affect the Euribor rates along the 3-month, 6-month, and 12-month horizon. As a result, excluding one of these risk components from the estimation equation would bear the problem of omitted variables.

Table B.2: Wald Test of Joint Hypothesis

H_0: $\beta_1 = 0, \beta_2 = 0, \beta_3 = 0$				
	Pre-crisis		Crisis	
$\Delta R(k)$	F-statistic	p-value	F-statistic	p-value
$k =$ 3-month	25.08	0.00	5.57	0.00
$k =$ 6-month	247.89	0.00	3.03	0.02
$k =$12-month	245.60	0.00	12.11	0.00

[24] More precisely, the formula for the F-statistic adjusts for potential correlation so that, under the null hypothesis with q restrictions, the F-statistic has an $F_{q,\infty}$ distribution in large samples whether or not t-statistics are correlated.

C Unit Root Tests

This annex provides results regarding the co-integration properties of the data. Therefore, we perform unit root tests on the Euribor and OIS rates for which the Augmented Dickey-Fuller *t*-statistics are presented in Table C.1. For both the pre-crisis and crisis period, the Euribor and OIS rates of all considered maturities have a unit root, i. e. are I(1), and should thus be treated as non-stationary variables. To avoid the issues associated with non-stationarity, the Euribor and OIS rates should be expressed in first differences.

Table C.1: Unit-Root Tests

Variable	ADF Test		Variable	ADF Test	
	Pre-crisis	Crisis		Pre-crisis	Crisis
$R(3)$	-0.89	-1.24	$\Delta R(3)$	-24.34***	-5.89***
$R(6)$	-1.15	-0.98	$\Delta R(6)$	-26.59***	-7.35***
$R(12)$	-1.11	-0.74	$\Delta R(12)$	-28.33***	-8.63***
$OIS(3)$	-1.29	-1.23	$\Delta OIS(3)$	-30.76***	-6.87***
$OIS(6)$	-1.22	-0.90	$\Delta OIS(6)$	-31.58***	-19.56***
$OIS(12)$	-1.21	-0.94	$\Delta OIS(12)$	-29.02***	-21.50***

Notes: *** denote the significance at 1 % critical value. The t-statistic of the Augmented Dickey-Fuller (ADF) tests refer to the following test equation with a constant, a linear trend and the lag length according to the Schwarz Information Criterion. However, all results are robust against variation of the lag length or the deterministics in the equation.

D Structural Break Test

This section uses structural break tests to investigate whether the period after August 9, 2007 significantly changed the dynamics of Euribor rates. To that aim, the Chow breakpoint test is applied to the equation of the Euribor, compare equation (1):

$$\Delta R_t(k) = \alpha(\frac{1}{k}\sum_{j=0}^{k-1} E_t \Delta r_{t+1+j}) + \beta' \Phi_t(k) + \gamma' CB_t + \delta' X_t + \sum_{j=1}^{5} \varphi_j \Delta R_{t-j}(k) + \epsilon_t \quad (2)$$

We divide our sample from March 10, 2004 to June 30, 2009 into two subsamples and test whether there has been a break in all the equation parameters α, β, γ and φ_j as of August 9, 2007. The Chow breakpoint test compares the sum of squared residuals obtained by fitting equation (2) to the entire sample with the sum of squared residuals obtained when separate equations are fit to each subsample. We report three test statistics for the Chow breakpoint test. The F-statistic is based on the comparison of the restricted and unrestricted sum of squared residuals. The *log likelihood ratio* statistic is based on the comparison of the restricted and unrestricted maximum of the (Gaussian) log likelihood function. The Wald statistic is computed from a standard Wald test of the restriction that the coefficients on the equation parameters are the same in all subsamples. While the F-statistic has an exact finite sample F-distribution, the *LR* and *Wald* test statistic have both an asymptotic χ^2 distribution with k degrees of freedom, where k is the number of parameters in the equation.

$\mathcal{H}_0$: No break at specified breakpoint			
Statistic	Euribor		
	3-Month	6-Month	12-Month
F (08/09/2007)	14.90 (0.0000)	36.60 (0.0000)	78.89 (0.0000)
LR	183.61 (0.0000)	382.52 (0.0000)	714.04 (0.0000)
$Wald$	130.25 (0.0000)	268.97 (0.0000)	372.23 (0.0000)

Notes: Specified break date and p-values in parenthesis. Subsamples: March 10, 2004 to August 8, 2007 and August 9, 2007 to June 30, 2009 for the daily Euribor of three-month, six-month, and twelve-month horizon.

The results confirm that the dynamics of Euribor rates have significantly changed since mid 2007. For all maturities, the test statistics strongly reject the null hypothesis of no structural change as of August 9, 2007.