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NONLINEAR LIQUIDITY ADJUSTMENTS IN THE EURO AREA OVERNIGHT MONEY MARKET

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In 2012 all ECB publications feature a motif taken from the €50 banknote.

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Abstract

The market-oriented approach promoted by the European Central Bank in the design of its refinancing operations creates incentives to credit insitutions to use actively the interbank market to manage their liquidity needs. In this context, we examine the ability of the overnight segment to guarantee the timely provision of unsecured funds to banks to smoothly absorb their liquidity shocks. This paper specifically focuses on the speed of reversion of transaction costs and available depth to their equilibrium levels in this market for overnight unsecured funds from 4 September 2000 to 31 December 2007. The reported evidence points to time-varying liquidity adjustments and identifies liquidity, market activity and the institutional setting of the ECB's refinancing operations as significant determinants of the observed resiliency regimes. Our analysis also shows how the speed of mean reversion of market liquidity, by affecting the level and the volatility of the overnight market rate, also affects the anchoring of the yield curve in the euro area.

Keywords: Overnight money market, market microstructure, transaction costs, price impact, mean reversion, financial turmoil.

JEL classification: C22, C25, G01, G10, G21, E52

Non-technical summary

From the viewpoint of the central bank, it is crucial to ensure a well-functioning money market since this market is the primary source of short-term funds for banks in all countries. As recently illustrated by the current financial crisis that started in August 2007, increased tensions in the money market – reflecting uncertainty of market participants – may rapidly lead to market disruptions, which can in turn endanger the transmission of the monetary policy stance along the yield curve. It is thus essential to observe and to understand the dynamics in the money market in general, and in its overnight segment in particular. It is especially important in the context of the euro area where the ECB through the Eurosystem plays a central role as primary liquidity provider to financial institutions.

In this context, this paper analyses the ability of the overnight segment to ensure the continuation of transactions between banks by providing stable liquidity conditions (and hence, to guarantee the ability to trade) to market participants in both normal and stress periods. Put it differently, this paper addresses the resilience, i.e. the ability of the market to guarantee the timely provision of unsecured funds, of the overnight segment of the euro area money market. It does so using data from 4 September 2000 to 31 December 2007. In this regard, the role of the ECB as liquidity provider in this market is also analysed through its potential impact on the market dynamics coming from the changes into the design of its operational framework (which took place on 10 March 2004) and its increased intervention during the first stage of the financial crisis, i.e. as of August 2007.

Using various indicators borrowed from the literature on microstructure, the following findings are reported. First, it is shown that the introduction of the current design of the operational framework improved the functioning of the market in terms of resilience, even when banks face increasing pressures for balancing their reserves at the end of the reserve maintenance period. Second, we also show how the time-varying speed of reversion of market liquidity to its long-term average, by impacting the level and the volatility of the overnight market rate, also affects the anchoring of the yield curve and the transmission of monetary policy decisions to money market interest rates. With respect to the first stage of the financial crisis, it appears that the increased intermediation role of the ECB has certainly encouraged market participants to continue to trade and provide liquidity in a more costly and volatile environment.

1 Introduction

The crucial role played by the money market as regards the continuation of payment flows (and ultimately lending to the economy) became obvious with the 2007-2012 financial crisis. As the recent experience has demonstrated, financial distress in the money market may lead to a breakdown of interbank transactions while a prolonged illiquidity situation of banks can rapidly damage their solvency. Central banks thus carefully monitor the well-functioning of the money market since this appears of utmost importance to ensure the smooth transmission of monetary policy signals along the yield curve. In this context, this paper analyses the ability of the overnight segment to provide stable liquidity conditions (and hence, to guarantee the ability to trade) to market participants in both normal and stress periods.[1]

In the euro area, monetary policy decisions are implemented according to precise rules[2] which design the so-called operational framework for the monetary policy of the Eurosystem. Following a market-oriented approach, these rules aim notably at creating an active money market between the refinancing operations of the European Central Bank (ECB). The Eurosystem's operational framework therefore creates strong incentives to encourage credit institutions to manage their reserves directly through the interbank market with a view to ending the maintenance period in a balanced position. In this respect, the overnight segment of the euro area money market plays an essential role since it connects cash-poor banks to cash-rich counterparties to meet their short-term liquidity needs between the refinancing operations of the ECB. Against the backdrop of the financial turmoil that started in the summer 2007 over which the volume exchanged in the interbank market decreased markedly, the ability of this market to guarantee the timely provision of unsecured funds under quiet and more stressful conditions therefore takes on particular importance.

The aforementioned considerations explain why central banks stand ready to take the necessary measures to guarantee a well-functioning money market should

[1] Market liquidity traditionally has three dimensions: tightness (transaction costs), depth, and resiliency. The latter captures the temporal dynamics of its first two dimensions (see, e.g., Kyle (1985)).

[2] See ECB (2011).

temporary or permanent market disturbances arise (e.g., in case of financial distress). In the specific case of the ECB, various events support this view over the sample considered in this paper. On the one hand, a new design of the operational framework was introduced in March 2004 to address the persistent volatility of the overnight market rate. On the other hand, the financial turmoil episode has triggered increased interventions by the ECB through a series of one-day fine-tuning operations to provide additional central bank reserves to the banking sector. This paper therefore focuses on two particular issues. First, we examine how the operational framework interacts with the speed of mean reversion of money market liquidity. Second, we explore the role played by the resilience of market liquidity in the transmission of the monetary policy stance to money market rates.

In a number of recent papers, the speed of convergence to stable liquidity conditions has been inferred from the number of quote updates required for transaction costs or market depth to return to their pre-shock levels (Degryse, De Jong, Van Ravenswaaij and Wuyts 2005, Wuyts 2012) or from the probability that liquidity is restored before the occurrence of a new transaction (Foucault, Kadan and Kandel 2005). In the mean reversion framework set up in Kempf, Mayston and Yadav (2009), this temporal dimension of market liquidity can be quantified, which opens the way for new investigations of its dynamics over time or across assets. Examinations of the resilience of order book liquidity nevertheless form the most significant part of the literature, which mostly focuses on the stock market.[3] The speed of mean reversion of liquidity parameters under other market configurations, like in the money market where utilitarian motivations dominate other motivations to trade, nevertheless remains an open question.

Against this background, our contribution to the literature is essentially twofold. First, we check whether the central bank can interfere with market liquidity in a way that makes the money market more (or less) attractive to credit institutions to meet their needs for short-term funds. More specifically, we examine how the design of the operational framework for the implementation of monetary policy decisions affects the speed of reversion of transaction costs and market depth to

[3]For further details, see in particular Gomber, Schweickert and Theissen (2004) or Kempf et al. (2009) on the German Xetra stock market, Degryse et al. (2005) at Paris Bourse, or Large (2007) on SETS at the London Stock Exchange.

their equilibrium levels. In particular, we assess the stability of resiliency over time and look for evidence of nonlinear liquidity adjustments in the overnight segment of this market. We notably report that while resiliency drops markedly as banks face increasing pressures for balancing their reserves in the unsecured overnight market, the introduction of the current design of the operational framework in March 2004 leads to faster mean reversion of spreads and depth. Second, we show how the time-varying speed of mean reversion in market liquidity, by impacting the level and the volatility of the overnight market rate, also affects the anchoring of the yield curve and the transmission of monetary policy decisions to money market rates. To the best of our knowledge, this is the first paper that deals with these specific issues. While recent papers essentially focus on equity markets, we address the issue of the resilience of liquidity in the money market for the first time. Unlike previous research, we draw our conclusions from several years of high-frequency data (i.e., using data from 4 September 2000 to 31 December 2007) and the robustness of our findings is reinforced through a systematic examination of several high- and low-frequency transaction cost and price impact estimators. As we discuss, our results are also robust to alternative model specifications.

The remaining of this paper is organised as follows. We give a brief overview of the design of the euro area money market in Section 2. Section 3 describes the data for interbank transactions and the estimators of market liquidity used in our analysis. The speed of mean reversion of spreads and depth in the overnight money market is examined in Section 4, where we also identify determinants of the time-varying dynamics of liquidity in this market. Section 5 checks the sensitivity of market quality to the speed of mean reversion in spreads and depth. We conclude in Section 6.

2 The Importance of the Central Bank's Refinancing Operations Within the Euro Area Money Market

The money market is the primary source of short-term funds for banks in all countries. In the euro area, a bank's needs for short-term funds is determined by its reserve requirements and the autonomous factors. Credit institutions are indeed obliged to hold minimum reserves (calculated on the basis of the size of their short-term liabilities) at the central bank on average over a specific period of time called the reserve maintenance period (RMP), which is roughly equivalent to one calendar month.[4] Autonomous factors include banknotes in circulation, deposits of governments in the national central banks of the euro area, domestic and foreign assets held by national central banks and other assets. While the reserve requirements are known in advance[5], the evolution of the autonomous factors is more subject to unexpected shocks. Even if financial institutions can extrapolate regular trends in the evolution of most components of these factors (especially banknotes and government deposits) from the past behaviour of their customers, empirical evidence shows that these items remain subject to deviations from regular trends, hence constituting shocks which lead to unexpected (positive or negative) needs for short-term funds. These (unexpected) shocks to autonomous factors may be either idiosyncratic (i.e., affecting the cash position of an individual bank without necessarily impacting the cash position of other banks) or global (i.e., affecting the cash position of all market participants in the money market at the same time; see Durré (2007) for further details). These shocks are particularly significant on specific days where the flow in payment systems is more tense. This phenomenon is usually summarised by the so-called calendar (day) effects (or patterns) during which banks' demand for short-term funds is more pronounced due to the related uncertainty associated with the flows of payments (e.g., at the end of a month, quarter, semester or at the end of a year).

When implementing the decision of the Governing Council on the level of the policy rate (i.e., the minimum bid rate for the refinancing operations of the central bank), the ECB aims to supply the money market with the necessary short-term funds for the banking system to operate smoothly in such a way that very short-term money market interest rates remain appropriately aligned with the monetary

[4]According to the Statute of the European System of Central Banks (ESCB), all credit institutions established in the euro area are subject to the minimum reserve system. These reserves are remunerated over the RMP at the average of the marginal rate on the Eurosystem's MROs. The reserve requirements are determined by the amount of the corresponding institution's liabilities with a maturity up to two years and exceeding EUR 100,000. For further details about the specific features of the Eurosystem's operational framework, see ECB (2011).

[5]Indeed, the balance sheet data of each institution subject to reserve requirements referring to the end of a given calendar month are used to calculate the reserve base for the maintenance period starting in the calendar month two months later (see ECB (2011)).

policy stance signalled by the Governing Council. Injections of short-term funds by the ECB accordingly target neutral cash conditions in the money market over the whole reserve maintenance period. In other words, the injections of cash by the ECB should not constitute additional monetary impulses but should simply reflect the monetary policy stance decided by the Governing Council. In normal times, the ECB's approach to monetary policy implementation relies largely on self-regulating market mechanisms through a rather limited presence in the money market with only few (mostly weekly) operations. The main motivation behind this approach is to ensure the existence of an active money (or interbank) market by maintaining over time sufficient incentives to encourage banks to trade with each other from the shortest to the longest maturity. This notably supports the relative large size of the interest rate corridor in the euro area of 200 basis points (in normal times) formed by the interest rate on the marginal lending facility (i.e., the highest ECB interest rate) and the interest rate on the deposit facility (i.e., the lowest interest rate). When banks need more funds than those provided by the ECB or need funds between the ECB's interventions, the overnight (uncollateralised) segment of the money market is thus the natural place to find short-term funds from cash-rich banks to avoid the recourse to ECB's emergency (marginal or deposit) facilities at a penalty rate (of +/- 100 basis points with respect to the policy rate). From a microstructure perspective, this therefore supports the utilitarian nature of the overnight segment according to which banks essentially trade to meet their liquidity needs (mostly driven by reserve requirements and payment flows) so that the proportion of informed traders is expected to remain low in this market (Furfine 1999, Iori, De Masi, Precup, Gabbi and Caldarelli 2008).

By nature, the central bank's operational framework is thus the initial link between the key ECB interest rates and the market interest rates through which the monetary policy stance is transmitted to other financial instruments and credit institutions. In this regard, narrow spreads between short-term money market rates and the policy rate appear essential to ensure a smooth transmission of monetary policy decisions along the yield curve. In the specific case of the overnight segment in the money market, it is especially important that the spread between the overnight interest rate (including the EONIA and the overnight rate on the e-

MID platform) and the policy rate of the ECB is tight and stable over time. Large and possibly widening spreads would indeed trigger a deterministic deviation of short-term interest rates from monetary policy decisions, which could in turn lead to increasing risk premia along the yield curve, hence undermining the monetary policy transmission mechanisms. In the same vein, excessively volatile spreads would also undermine the clarity of the signal provided by the level of the policy rate and ultimately the credibility of the central bank's operational framework. In short, the volatility of the overnight interest rate caused by its reactiveness to liquidity conditions in the money market should not propagate through the yield curve. This appears a prerequisite for interest rates of term maturities to adequately reflect market expectations of the future path of the policy rate and to have the desired influence on the economic outlook. This is not only a concern for policymakers but also for investors since any uncertainty about the exact information content of market rates would complicate the pricing of most financial instruments.

Since the introduction of the euro in January 1999, the Eurosystem's operational framework appears to have functioned smoothly overall. However, some challenges have emerged on occasions and procedures have been adapted to nullify (or at least to limit) their impact in the money market (see Durré and Nardelli (2008)). In particular, the growing occurrence of underbidding episodes led to significant changes in the operational rules defining the implementation of the monetary policy in the Eurosystem. As explained in Durré and Nardelli (2008), underbidding, by causing imbalanced liquidity conditions, raised the volatility of the overnight market rate. This especially appeared when market participants expected key ECB interest rates to be cut, and hence delayed their accumulation of reserve holdings to meet required reserves in anticipation of more favourable interest rate conditions. As a result, they reduced their participation to weekly ECB's refinancing operations that have occasionally failed to inject the necessary liquidity to ensure a smooth functioning of the banking system, leading to higher overnight interest rates. The following changes were thus introduced on 10 March 2004. First, the timing of the reserve maintenance period was changed so that a maintenance period always starts on the settlement day of the main refinancing operation following the Governing Council meeting at which the monthly assessment of the monetary policy stance is pre-scheduled. Second, changes to the standing facility rates are implemented at the start of the new reserve maintenance period. Finally, the maturity of the main refinancing operations was shortened from two weeks to one week. As reported in Durré and Nardelli (2008) or Beaupain and Durré (2008), these structural changes have significantly altered the dynamics of the overnight segment. In particular, these changes have led to a situation in which expectations of key ECB interest rates are flat over the entire maintenance period, and there are thus no more incentives for underbidding. For a detailed description of the operational framework and its link to the segments of the money market, see ECB (2003), ECB (2008), or Beaupain and Durré (2008).

Further research reports how the operational frameworks of central banks drive the dynamics of interbank money markets (see, e.g., Hamilton (1996) or Pérez Quirós and Rodríguez Mendizábal (2006)). More specifically, the literature documents how the rules defining the implementation of the monetary policy decisions contained in the frameworks make the overnight market rate particularly sensitive to the level of stress faced by market participants. In this respect, more binding reserve requirements towards the end of the maintenance period notably raise the volatility of the market for short-term funds (see, e.g., Spindt and Hoffmeister (1988), Eagle (1995), Griffiths and Winters (1995), Bartolini, Bertola and Prati (2001), and Bartolini, Bertola and Prati (2002) for the fed funds, or Hartmann, Manna and Manzanares (2001), Benito, León and Nave (2007), Gaspar, Pérez Quirós and Rodríguez Mendizábal (2008), Cassola, Durré and Holthausen (2011), and Cassola, Hortacsu and Kastl (2011) for the money market in the euro area). Similar forces drive the intraday operation of those markets. Market activity clusters at both ends of the trading session (Angelini 2000, Cyree and Winters 2001, Hartmann et al. 2001, Bartolini, Gudell, Hilton and Schwarz 2005). Volatility peaks near the close of trading when market participants face high pressure for finding the necessary short-term funds to end the day in a balanced position (Spindt and Hoffmeister 1988, Griffiths and Winters 1995).

As shown by these studies, and even more recently by the financial crisis that started in August 2007, the central bank is thus in a position to influence the dynamics of the money market (in both the activity and prices terms) by either increasing or decreasing its intermediation role. Whether the central bank can interfere with the dynamics of overnight market liquidity in a way that enhances the speed of convergence of transaction costs and market depth to their equilibrium levels is an open question that takes on particular importance in the European context.

3 Data: Definition and Treatment

In the euro area, interbank transactions are alternatively executed electronically or over-the-counter (mainly in the form of bilateral deals or through voice brokers). Empirical evidence reported in previous research shows that the order flow captured by the e-MID electronic platform is representative of the dynamics of the whole money market (Beaupain and Durré 2011), which alleviates our concerns about sample selection bias. The relative order flow captured by the electronic platform further remained stable (with respect to the trades executed over-the-counter) until the collapse of Lehman Brothers. Data for the orders filled on the platform is accordingly provided by e-MID and contains records of all overnight transactions executed through their systems.[6] When a trade occurs, a new record is created that reports the date, time, price, size and side of the deal (i.e., buy or sell). Our sample covers the period from 4 September 2000 to 31 December 2007. Erroneous records and extreme outliers are removed from the raw tick-by-tick data provided by the platform.[7] In spite of more stable market conditions in the euro area between January and August 2008, the period beyond December 2007 was not incorporated in our sample for the following reasons. First, credit institutions may have been more reluctant to disclose any liquidity shortage in a transparent way (through the platform) while central banks around the world were injecting massively liquidity in the market. Second, as a related matter, banks' solvency has also become more uncertain. In reaction, while small- and

[6] See Beaupain and Durré (2011) for a detailed description of the functioning of the electronic platform.

[7] The records for which a date, time, price or quantity is missing or negative are removed. Deals with a price recorded outside the corridor defined by the ECB's marginal lending and deposit rates are filtered out. Finally, trades executed before 08:30:00 or after 18:00:00 are not included in the filtered data set.

medium-sized banks remained active on the electronic platform, anecdotal evidence suggests that some big market participants tended to move to the more opaque over-the-counter channel for the provision of unsecured liquidity, where they only disclosed their liquidity needs to selected counterparties. Third, growing concern about potential price pressures in the medium term has motivated a 25 bps increase of the key ECB interest rates on 3 July 2008. Finally, the introduction of a fixed-rate full-allotment procedure by the ECB to offset market distortions following the collapse of Lehman Brothers on 15 September 2008 has radically affected the operation of this market.

In this paper, we examine the temporal dynamics of the first two dimensions of market liquidity identified in the theoretical literature (Kyle 1985), that is, tightness and depth. For this purpose, the cost of trading in this market is inferred from high-frequency and low-frequency spread estimators. Price impact, that is, the reaction of prices to the volume of transactions executed in the market, is similarly used to approximate market depth. Although, due to the utilitarian nature of the transactions executed in this market, informed trading is expected to remain relatively low, we cannot however reject that on some occasions market participants trade for informed reasons. We therefore systematically check the robustness of our findings across different alternative measures of market liquidity which are known for incorporating asymmetric information in different ways (see Goyenko, Holden and Trzcinka (2009) or Hasbrouck (2009) for an assessment of their relative performance). The absence of significant differences between liquidity measures would accordingly suggest that informed trading does not bias our results. All our estimators are computed at the daily frequency. Where applicable and unless otherwise mentioned, we use Goyenko et al.'s (2009) definitions.

3.1 Transaction Costs

Roll's (1984) implicit effective spread. Roll (1984) introduces a method for inferring the effective spread from the first order serial covariance of price changes. In the spirit of Stoll (2000), this implicit spread is extracted from price changes observed over consecutive transactions (Δp_t) and Roll's (1984) estimator is accordingly computed as:

$$ROLL = \begin{cases} 2 \times \sqrt{-Cov_d(\Delta p_t, \Delta p_{t-1})} & \text{if} \quad Cov_d(\Delta p_t, \Delta p_{t-1}) < 0 \\ 0 & \text{otherwise} \end{cases}$$

where Cov is the first order serial covariance.

Stoll's (2000) traded spread. The traded spread is measured as the difference between the average price of buy transactions (i.e., trades hitting the ask) and the average price of sell trades (i.e., executed on the bid side of the market) (Stoll 2000). We accordingly compute the traded spread from the transactions executed on the electronic platform. The equally-weighted average traded spread (EWTS) gives an equal weight to all transactions and is computed as:

$$EWTS = \frac{1}{B} \times \sum_{b=1}^{B} p_b - \frac{1}{S} \times \sum_{s=1}^{S} p_s$$

where p_b (resp. p_s) is the price of the b^{th} buy trade (resp. s^{th} sell trade) executed in the market.

We alternatively construct a time-weighted average traded spread (TWTS) in which the weight of each observation is a function of the number of seconds before a new transaction occurs on the same side of the market (i.e., a function of the time the related quote remains unchanged in the market), that is,

$$TWTS = \frac{\sum_{b=1}^{B} \omega_b p_b}{\sum_{b=1}^{B} \omega_b} - \frac{\sum_{s=1}^{S} \omega_s p_s}{\sum_{s=1}^{S} \omega_s}$$

where ω_b (resp. ω_s) is the number of seconds between trade b and $b+1$ (resp. s and $s+1$).

Huang and Stoll's (1996) realised spread. The realised spread captures the temporary component of the effective spread and is here measured as:

$$EWRS = \frac{1}{T}\sum_{t=1}^{T} 2 \times D_t \times (p_t - p_{t+5})$$

where D_t is 1 (resp. -1) if the t^{th} transaction is a buy (resp. sell), p_t is the price of trade t and p_{t+5} is the price of a transaction executed 5 minutes after trade t.

3.2 Price Impact

Amihud's (2002) illiquidity ratio. Amihud (2002) shows that the illiquidity of a market is a function of the absolute change in the price in reaction to a given volume of transaction. The illiquidity ratio of day d is accordingly computed as:

$$AMIHUD_d = \frac{|\Delta p_d|}{Q_d}$$

where Q_d is the total volume exchanged on day d.

Kyle's (1985) lambda. While Amihud's (2002) illiquidity ratio captures the reaction of prices to exchanged volumes on a daily basis, it fails to capture the intraday reaction of the price to the size of the transactions. This however takes on particular importance when banks split their orders in smaller parts to avoid the market inferring information on their specific liquidity needs. This appears even more relevant against the confidence crisis experienced over the recent turmoil episode, during which market participants became extremely reluctant to disclose their full positions on transparent systems to avoid the market misinterpreting their financial needs. To gain further insight into this dimension, we estimate Kyle's (1985) lambda from 5-minute price changes (Δp_t) and trade imbalances ($IMBAL_t$):

$$\begin{aligned} \Delta p_t &= \lambda IMBAL_t + \varepsilon_t \\ \text{where} \quad IMBAL_t &= \textstyle\sum_{t=1}^{T} D_t \sqrt{Q_t} \end{aligned}$$

where the daily λ estimate is a measure of the 5-minute impact of trades on prices for day d (hereafter $KYLEL_d$).

Descriptive statistics for our liquidity proxies are reported in Panel A of Table

1. While Roll's (1984) implicit spread is wider than Stoll's (2000) alternatives, all effective transaction costs (ROLL, EWTS, and TWTS) exhibit similar standard deviations. As expected, the temporary component of the spread (EWRS) is on average weaker than the other spread proxies. The pairwise correlation coefficients provided in Panel B of Table 1 point to strong co-movements across our liquidity proxies. In spite of their specific characteristics, our spread measures (ROLL, EWTS, TWTS, and EWRS) are highly correlated among themselves. Correlation is highest between ROLL and TWTS (0.9200) and weakest between EWTS and EWRS (0.6947). Correlation remains high across depth proxies (AMIHUD and KYLEL), with a coefficient of 0.6608. Both liquidity dimensions tend to move in the same direction: wide spreads are generally associated with low depth conditions.

4 Resiliency

The class of mean reversion models developed in the literature examines the speed of convergence of market parameters to their long term averages (see, e.g., Cheung and Lai (1994), Frankel and Rose (1996) or Sollis, Leybourne and Newbold (2002) for real exchange rates or Balvers, Wu and Gilliland (2000), Chaudhuri and Wu (2003) or Gropp (2004) for equity prices). In such specifications, the estimated speed of mean-reversion reflects the ability of the parameter to return to equilibrium after being shocked. This class of models is used to examine the speed of mean reversion in liquidity proxies for the first time in the pioneering work of Kempf et al. (2009), where the authors observe the dynamics of the limit order book in the German Xetra stock market. The strength of resiliency is accordingly defined as the magnitude of the mean reversion in liquidity proxies. To examine the resilience of transaction costs and depth in the overnight segment of the money market, we adopt a similar specification, which takes the following form:

$$\Delta L_d = \alpha - \beta L_{d-1} + \sum_{n=1}^{N} \gamma_n \Delta L_{d-n} + \varepsilon_d \qquad \varepsilon_d \sim i.i.d.(0, \sigma^2) \tag{1}$$

where L_d is the liquidity estimator (i.e., transaction cost or market depth) for day d, β proxies for resiliency and $n = 1, ..., N$ stands for the number of lags of the dependent variable included in the model. As the authors demonstrate, resiliency is strong when tightness or depth quickly revert to their long-term averages. In other words, resiliency improves as β converges towards 1.[8] The specification in Eq. (1) is also similar to an augmented Dickey-Fuller equation. The significance of the β coefficient is thus determined on the basis of the specific set of critical values in Dickey and Fuller (1979). Up to 20 lags of the dependent variable are included in the model, which broadly corresponds to the average duration of one reserve maintenance period. The optimal number of lags is chosen so that information criteria are minimised. When information criteria diverge, we adopt the most parsimonious specification.

Over the whole sample (i.e., from 4 September 2000 to 31 December 2007), the evidence reported in Panel A of Table 2 shows that depth proxies converge more rapidly to their long-term averages than our transaction cost estimators. While spread resiliency ranges from 0.2997 (EWRS) to 0.3704 (ROLL), the coefficient of mean-reversion in depth is significantly larger: from 0.5526 for KYLEL to 0.6147 for AMIHUD. The null hypothesis of equal speeds of mean reversion across our measures of transaction costs cannot be rejected at the usual significance levels. Similar results are found across estimators of market depth. Consistent with our expectations given the utilitarian nature of this market, this therefore confirms that trading by informed traders does not significantly affect the temporal dynamics of liquidity in the overnight segment. By contrast, spread resiliency diverges significantly from depth resiliency. In spite of the specific features of the overnight segment of the money market, this latter finding is consistent with the limited evidence reported in the literature on the time dimension of market liquidity (see, e.g., the empirical evidence reported in Degryse et al. (2005) for the limit order book at Paris Bourse where depth similarly appears more resilient than spreads following the execution of aggressive orders, or the asymmetric speeds of

[8] More specifically, β is expected to lie between 0 and 1, where a value of 1 implies that shocks to the liquidity estimator in one period are fully corrected in the next period (liquidity fully converges to its long-term average) and a value of 0 means that shocks are not corrected over time (the unit root case). Imperfect mean reversion occurs when the value of β lies between those 2 boundaries.

reversion of spreads and depth to their long-term averages reported by Marshall, Nguyen and Visaltanachoti (2012) for a sample of commodity futures).

In light of the considerations raised in Section 2 regarding the influence of the operational framework on the dynamics of the overnight segment of the money market, we split our sample into two sub-periods. Sample 1 accordingly covers the period from 4 September 2000 to 9 March 2004 and Sample 2 goes from 10 March 2004 to 31 December 2007. The experience of the recent market turbulence offers an opportunity to gain more insight into the behaviour of liquidity under quiet and more stressful market conditions. We thus split Sample 2 into two subperiods: Sample 2 (Quiet) accordingly covers the period from 10 March 2004 to 7 August 2007 and Sample 2 (Turmoil) is defined as the period from 8 August 2007 to 31 December 2007. This latter sub-sample characterises the dynamics of liquidity on the electronic platform over the first stage of the financial turmoil that shocked the overnight money market in mid 2007.

Resiliency estimates across sub-samples are reported in Panel B of Table 2. The resilience of liquidity strengthened between Sample 1 and Sample 2 (Quiet): 3 of our 4 spread proxies revert significantly more quickly to their long-term averages under the current design of the operational framework (the resiliency of EWRS is statistically similar in the 2 sub-samples). Depth is also more resilient in Sample 2 (Quiet), compared to its speed of mean reversion in Sample 1.

Transaction costs appear less resilient under heightened pressure for finding overnight liquidity (Sample 2 – Turmoil): spreads revert more slowly to their long-term averages in Sample 2 (Turmoil) where the magnitude of our β coefficients dropped below their values in Sample 1. Under stress, depth remains more resilient than spreads. While depth converges more quickly to its equilibrium level after March 2004, depth resiliency weakens under stress. The evidence on the speed of mean reversion of market depth in Sample 2 (Turmoil) is however mixed. Depth resiliency indeed slows down to a level below (AMIHUD) or similar (KYLEL) to its level before March 2004. During the first stage of the financial turmoil, the regular provision of liquidity by the ECB was perceived as a growing intermediation role endorsed by the central bank, which eventually led to a situation of average excess liquidity. Two key elements however conditioned the decision of market participants to retain or lend their excess liquidity in the market: (i) the uncertainty about their own liquidity shocks, and (ii) the quality of potential borrowers. A stigma effect further increased the reluctance of banks to signal liquidity shortages to other market participants. At a given level of borrowers' quality, anecdotal evidence over the turmoil episode showed that market activity essentially clustered around some specific intraday intervals when patient investors submit orders subject to their assessment of their liquidity needs for the day and to the timing of central bank interventions. Therefore, although the daily resilience of depth on the electronic platform was on average weaker in Sample 2 – Turmoil (as suggested by Amihud's ratio), this has not prevented market depth to be more resilient within the trading day under stress, as suggested by the resilience of Kyle's indicator.

4.1 Resiliency Regimes

The above analysis suggests that resiliency is affected by the rules defining the implementation of monetary policy decisions in the Eurosystem and potentially exhibits a time-varying behaviour. To investigate this issue in greater details, we construct a Markov switching model which allows liquidity to switch between regimes of high and low resiliency. By contrast to the above analysis, the switch between mean reversion regimes is determined endogenously without a priori references to the Eurosystem's operational framework or to the dynamics of this market. Our Markov-switching mean reversion model is accordingly specified as:

$$\Delta L_d = \alpha_s - \beta_s L_{d-1} + \sum_{n=1}^{N} \gamma_{s,n} \Delta L_{d-n} + \varepsilon_d \qquad \varepsilon_d \sim i.i.d.(0, \sigma_s^2) \qquad (2)$$

where α_s is the regime-specific intercept, β_s is the regime-specific resiliency proxy and σ_s^2 is the regime-specific variance.[9] The model is estimated using Krolzig's (1997) MSVAR package in Ox 3.00 where the EM algorithm is used to achieve the maximisation of the likelihood function. We use the MSIAH model specification which allows different intercepts, coefficients and variances under the two regimes.

[9] See, e.g., Hall, Psaradakis and Sola (1999), Garino and Sarno (2004) or Kanas (2006) for a discussion of the statistical properties of this class of Markov-switching augmented Dickey-Fuller (or MS-ADF) models.

Our rationale for using a parsimonious 2-regime specification comes from empirical evidence of 2 stages in the dynamics of the overnight segment of the money market over the reserve maintenance period (see, e.g., Beaupain and Durré (2008)). The behaviour of banks in this market indeed appears significantly different over the last days (i.e., the days between the last main refinancing operation allotment of a reserve maintenance period and the end of that period) compared to the other days of the reserve maintenance period, which essentially reflects an increased pressure for finding liquidity as reserve requirements eventually become more binding. As a result, market participants become more impatient to trade in the interbank market to fill their needs for short-term funds. This, as Foucault et al. (2005) predict, in turn is expected to weaken the resilience of market liquidity and therefore affect the regime decomposition with a highly-persistent regime of strong resilience followed by a switch to a weakly resilient regime towards the end of the period. The model is estimated for the whole sample, and is constructed to include the number of lags of the dependent variable (i.e., N) which minimises information criteria.[10] The Markov switching model converges for the resiliencies of both the tightness and depth dimensions. Likelihood ratio tests further confirm the non-linear dynamics of both liquidity dimensions in this market: LR tests of linearity are always strongly significant using Davies's (1977) upper bound, rejecting the null hypothesis of a single regime of resilience. The results are reported in Table 3.

Spread resiliency is generally strong across our proxies (the mean reversion coefficient ranges from 0.7937 for EWRS to 0.9811 for ROLL) and occasionally switches to a regime of weaker mean reversion (with a coefficient of 0.4047 for TWTS to 0.4756 for EWTS). The regime of strong resilience (regime 1) captures more than 70% of all observations and is highly persistent: the probability of being in regime 1 on day d when day $d-1$ was already in regime 1, that is, p_{11}, is 89% for ROLL, EWTS and TWTS and increases to 91.02% for EWRS. With an average duration of 9.84 (TWTS) to 11.13 (EWRS) days, this regime of high

[10] Three information criteria are used (Akaike, Schwartz Bayesian and Hannan-Quinn). When information criteria diverge, we rely on the most parsimonious model specification. The regime decomposition is however insensitive to the number of lags used in the model: transition probabilities and the number of observations in each regime are very similar whatever the number of lags included in the model. The results are available from the authors upon request.

resilience is more persistent than regime 2 (where the duration ranges from 3.14 for EWRS to 4.01 days for ROLL). Spread resiliency is also more volatile in the regime of weak resilience: the standard error of the regression increases significantly between regime 1 and regime 2. A plot of the probability of high resilience over the reserve maintenance period reported in Figure 1 lends further support to the influence of the institutional setting of this market on the speed of mean reversion of transaction costs to their long-term averages. In normal markets (i.e., in Sample 1 and Sample 2 – Quiet), the probability of strongly-resilient spreads is generally high over the reserve maintenance period but deteriorates markedly as banks face more binding reserve requirements. The peak in market activity over the last days of the period caused by the averaging mechanism weakens the resilience of liquidity in the overnight segment. By contrast, the implementation of the current design of the operational framework has positively altered the dynamics of spread resiliency over the RMP: the daily probability of high resilience is generally higher in Sample 2 (Quiet) compared to its level in Sample 1. Under stress (in Sample 2 – Turmoil), the market becomes weakly resilient with a generally low probability of being in regime 1 over the entire period.

Depth resiliency delivers a similar picture. Two regimes are also clearly identified: the mean reversion in AMIHUD and KYLEL proxies is generally strong but sometimes deteriorates to reach a regime of weaker resilience. The Markov switching model classifies most days into regime 1: more than 79% of all observations fall into this regime of strong resilience. The standard error inflates markedly between regime 1 and regime 2, where the magnitude of depth resiliency is weaker. Similar to spread resiliency, regime 1 is on average more persistent than regime 2 (while the duration of regime 1 is close to 10 days, the duration of regime 2 is only about 2 days). The probability of high resilience on day d when resilience was high on day $d-1$ (i.e., p_{11}) is close to 90%, while the probability of staying in the regime of weak resilience on two consecutive days (i.e., p_{22}) drops to 58.95% for AMIHUD and 63.03% for KYLEL. As Figure 2 shows, the implementation of the monetary policy also affects depth resiliency: the probability of highly-resilient depth conditions drops markedly over the last days of the maintenance period. Unlike transaction costs, depth resiliency however appears less sensitive to more stressful market conditions, as observed over the recent market turbulence.

4.2 Regime Determinants

The above evidence hints at the presence of two regimes of spread and depth resiliency in the interbank market. The key issue is now to detect potential parameters that could increase (or decrease) the probability of being in one particular regime rather than the other. This part of our analysis relies on a probit model applied to the regime probabilities.[11] In this specification, an observation is assumed to belong to regime s if the probability of being in this regime on day d is greater than 0.5.[12]

Our set of potential regime determinants is defined as follows. First, as the model in Foucault et al. (2005) shows, market dynamics is expected to drive the speed of mean reversion of liquidity in order-driven markets. More specifically, their model predicts that resiliency is an inverse function of the size of the spread or of the order arrival rate (market activity) but increases with the proportion of patient traders or with waiting costs. The evidence reported in Kempf et al. (2009) lends early empirical support to these predictions in the German Xetra stock market. In particular, traders' patience and market activity are significant determinants of the intraday resilience of transaction costs for the DAX 30 stocks over the three month period examined by the authors. The reaction of depth resiliency is however opposite, which suggests that mean reversions in spreads and depth do not occur simultaneously within the trading day. The money market offers an opportunity to validate these results in an environment where strategic trading is expected to remain low. Unlike the OTC channel for liquidity provision, the electronic platform is designed as a limit order book which collects and processes electronically the orders submitted by market participants. Against this background, liquidity and market activity are used as control variables in our models. Second, given the specific design of this market, we include institutional

[11] See, e.g., Cousin and de Launois (2006) where this technique is used to investigate the determinants of volatility regimes.

[12] The results presented in the Tables are based on smoothed regime probabilities. Unreported tests using filtered probabilities brought very similar conclusions. The results are available upon request.

factors as potential regime determinants to examine how the operational framework for the implementation of the monetary policy interacts with the speed of mean reversion of money market liquidity.

Liquidity. Empirical evidence reported in the literature suggests that the three liquidity dimensions are interconnected (Dong, Kempf and Yadav 2007, Kempf et al. 2009). Wide spreads are typically associated with low depth conditions. Tight spreads and deep markets are similarly more resilient. We also expect a certain degree of persistence in resiliency: highly-resilient liquidity conditions on day d should favor high resilience on day $d+1$. We accordingly test the hypothesis that the past level of resilience affects its current level and that tight spreads and deep markets improve the resilience of liquidity conditions in the market.

Hypothesis 1: *Resiliency is persistent across days and is positively related to the other dimensions of market liquidity (i.e., transaction costs and the available market depth).*

In the probit model, we include as regime determinants (i) the size of the spread on day d, and (ii) the price impact proxy on day d. To control for regime persistence, we add up to 20 lags of the dependent variable, which broadly corresponds to the average duration of one reserve maintenance period in the euro area. The appropriate number of lags is chosen so that standard information criteria are minimised. When such criteria diverge, we select the most parsimonious model.

Market activity. Resiliency is expected to deteriorate as the order arrival rate increases, but to strengthen as traders become more patient (Foucault et al. 2005). In the same vein, liquidity (Coppejans, Domowitz and Madhavan 2004) and resiliency (Hmaied, Grar and Sioud 2006) tend to improve in more active markets. The available empirical evidence on the relation between resiliency and volatility (stress) is however not conclusive (see, e.g., Coppejans et al. (2004), Dong et al. (2007), or Kempf et al. (2009)) and therefore deserves a careful examination.

Hypothesis 2: *Resiliency strengthens as trading becomes more active, but deteriorates as banks become more reluctant to trade and as uncertainty (stress) increases.*

Market activity is approximated by the number of transactions executed in the market (NBTRD), and is an indirect proxy for the order arrival rate. The average quantity per trade (EWQTY) is an indicator of the reluctance to trade. The level of stress faced by market participants is captured by the realised volatility of the market rate (RVOLA).

Institutional factors. In light of the significant influence of institutional factors on the level and volatility of transaction costs and market depth (Barucci, Impenna and Renò 2004, Beaupain and Durré 2008), we check whether the rules defining the implementation of the monetary policy also affect their speed of convergence to their equilibrium levels. Among institutional factors, we examine the effect of the introduction in March 2004 of the current design of the operational framework in the Eurosystem. The deterioration of liquidity conditions observed around the main refinancing operations of the European Central Bank is also expected to negatively affect the resilience of spreads and depth in this market. Over the last days of the reserve maintenance period, liquidity is expected to become less resilient, mainly on the account of more binding reserve requirements. The uncertainty surrounding press conferences regarding the decisions made by the Governing Council of the ECB and hence the future path of interest rates is similarly expected to weaken the resilience of liquidity in this market.[13] Finally, a weaker resilience of spreads and depth should result from the confidence crisis observed among financial institutions over the first stage of the recent financial turmoil.

Hypothesis 3: *The resilience of spreads and depth has increased with the current design of the operational framework but generally deteriorates over the last days of the reserve maintenance period, during main refinancing operations, around press conferences and in particularly stressful market conditions (i.e., over the financial turmoil).*

The influence of institutional factors on the resilience of liquidity is investigated through the inclusion of a set of dummy variables controlling for the above effects.

As the literature suggests (see, e.g., Angelini (2000), Barucci et al. (2004),

[13]Due to the nature of the changes introduced to the operational framework in March 2004, the last days and press conference effects might differ under the former and current designs of the operational framework. Our model is specified accordingly.

Beaupain and Durré (2008), or Gaspar et al. (2008)), the institutional setting also influences the liquidity and activity of this market. We therefore remove the seasonality induced by the operational framework from the mean and variance of our proxies. For that purpose, we rely on Gallant, Rossi and Tauchen's (1992) technique (see Appendix A for more details). The evidence reported in Table 4 confirms the sensitivity of our spread and depth proxies to institutional factors: liquidity deteriorates (the mean and variance of our proxies increases) over the last days of the maintenance period, during main refinancing operations and over the recent financial turmoil, but has significantly improved with the introduction of the current design of the framework (the mean and variance of the proxies dropped significantly). Table 5 further shows that market participants face more stressful market conditions (RVOLA increases) and become more reluctant to trade large sizes (EWQTY drops) as trading becomes more active (NBTRD increases) during main refinancing operations and near the end of the maintenance period. While the new framework has improved the activity of the segment, the reported evidence highlights the negative effect of the recent market turbulence on the volatility and on the average size of the transactions executed on the platform. The deseasonalised proxies are used in the remaining of our analysis and therefore correspond to their unexpected component.

The determinants of spread resiliency regimes are reported in Table 6. In our probit models, the baseline regime is the highly-resilient regime (i.e., regime 1). Hence positive (resp. negative) coefficients point to a positive (resp. negative) relation between the variable and the regime of high resilience. All the tests reported in the Table are based on Huber-White robust standard errors. The reported evidence confirms the persistence of regimes of spread resiliency (the coefficients on the lagged regimes are always strongly significant, whatever the spread proxy used). While our tests confirm that unexpected increases in spreads tend to reduce the resilience of the first dimension of market liquidity, the significance of depth[14] as a determinant of spread resiliency is however mixed (the unexpected component of depth only significantly drives the resilience of EWTS and EWRS).

[14]For each regime of spread estimators (ROLL, EWTS, TWTS, EWRS), we examine separately the influence of the 2 price impact proxies (i.e., AMIHUD and KYLEL). The results lend further support to the robustness of our findings and are reported in Table 6.

An unexpected increase in order submission (NBTRD) or a stronger reluctance to trade large sizes (EWQTY) do not significantly alter the time dimension of transaction costs. This suggests that the current design of the market guarantees the provision of liquidity to market participants even under unexpectedly active market conditions. Unexpected increases in market stress tend to weaken spread resilience (ROLL, EWTS and EWRS resiliency regimes are all negatively related to the unexpected level of realised volatility). Consistent with our initial intuition and after controlling for the effect of liquidity and market activity, the speed of mean reversion in spreads is significantly affected by the institutional setting of this market. Spread resiliency indeed deteriorates as market participants face increasing uncertainty (over the main refinancing operations and over the recent market turbulence) or as reserve requirements eventually become more binding (i.e., over the last days of the maintenance period). Consistent with the nature of the changes introduced to the operational framework, press conferences make spreads less resilient before March 2004 and more resilient under the current design of the operational framework. In addition to lowering the cost of transacting in the market (Beaupain and Durré 2008), the new operational rules introduced in March 2004 have thus reinforced the resilience of spreads in this market (the coefficient for the new framework dummy variable, NF, is always positive and strongly significant across our proxies). The picture is very similar for all spread proxies, which confirms the robustness of those findings.

The speed of mean reversion in market depth is subject to similar forces. The evidence reported in Table 7 highlights the persistence of depth resiliency across days and its dependence on the contemporaneous depth available in the market. By contrast to the regimes of spread resiliency, unexpected increases in market stress (RVOLA) do not alter the ability of the market to provide liquidity (i.e., depth). The resilience of the 5-minute price impact (KYLEL) appears inversely related to the reluctance of banks to exchange large sizes through the platform. Finally, our tests confirm that institutional factors drive the resilience of the first (transaction costs) and second (depth) dimensions of market liquidity in a similar way.

In the above analysis, in an attempt to attenuate the potential measurement errors in the size of the probabilities estimated by the Markov switching mean reversion models, the raw probabilities were converted to binary regime variables. As a robustness check, we examine alternative model specifications.[15] First, we drop the lags of the dependent variable included in our initial model specifications. This approach confines the potential errors-in-probabilities to the left-hand side of the equation, so that such errors are fully captured by the error term of the model and consequently do not bias our coefficient estimates. A likelihood ratio test is then used to compare the fit of the restricted model to its initial specification. Second, we use the raw regime probabilities as the dependent variable in a standard OLS regression framework with robust standard errors and covariances, where the liquidity, activity and institutional factors identified above are used as explanatory variables. Third, we check the explanatory power of liquidity, market activity and the institutional factors separately. We accordingly run additional regressions where the raw and the binary-converted regime probabilities are used as dependent variables. Each alternative specification supports the robustness of the findings reported in this part of our analysis.

5 Market Quality in Resiliency Regimes

From a microstructure perspective, the ability of a market to operate smoothly under quiet and more stressful conditions takes on particular importance. This issue appears even more relevant for overnight transactions as the interbank market is the initial and primary source of unsecured funds for banks, which allows them to absorb smoothly short-term liquidity shocks. In this context, the spread between the overnight market rate and the policy rate of the central bank is of crucial importance since it reflects the market conditions at which banks can meet their needs for short-term funds. By nature, and given the purpose of the overnight segment, this spread is exclusively affected by liquidity conditions in the market, part of which is determined by the liquidity directly provided by the ECB through its auctions. Furthermore, its dynamics mechanically influence the other segments of the money market yield curve through arbitrage mechanisms. In particular, a

[15] Due to space constraints, the results are not reported in the paper but remain available from the authors.

stable market spread preserves the dynamics of interest rates from wrong policy signals, and hence ensures a better anchoring of the money market yield curve. By contrast, more volatile spreads may eventually increase risk premia along the yield curve: arbitrage transactions through derivatives become more difficult to execute, which in turn negatively affects the anchoring of the yield curve and the dynamics of this market, hence undermining the transmission of monetary policy decisions along the yield curve.

Market participants thus have strong incentives to monitor this spread on a daily basis. From the practitioner's viewpoint, this may help to anticipate future disturbances in money market rates. From the policymaker's viewpoint, the dynamics of this spread may indicate the need for increased intervention to avoid wrong policy signals along the yield curve, and hence to ensure the smooth transmission of the monetary policy decisions.

The distribution of the market spread across regimes of transaction costs and depth resiliency is examined in Panel A of Table 8. In this Table, we consider the absolute proportional deviation between the policy rate of the ECB and the average price of the transactions executed by the largest market participants (i.e., the EONIA spread). The reported evidence confirms the sensitivity of this spread to the speed of mean reversion of market liquidity. Under the strongly-resilient regime, it is on average significantly tighter and less volatile. A weaker resilience of trading costs or depth negatively affects the size (mean and median) and variability (standard deviation) of the market spread. The picture is very similar for all liquidity proxies examined in this paper. We further assess the sensitivity of the EONIA spread to the regime of resiliency following changes to the implementation of the monetary policy in March 2004 and also in the first stage of the financial turmoil. The results are reported in Panel B of Table 8 where the market spread is regressed on dummy variables for each subsample considered in this paper and for the regime of high resilience in our liquidity estimators. To further capture its persistence across days, one lag of the dependent variable is added.[16] The results in Table 8 confirm the significant relationship between the EONIA spread and the

[16]Note that the results are however insensitive to the inclusion of one lag of the dependent variable and/or to the use of raw regime probabilities rather than dummy variables to capture the regime of high resilience. The results are available upon request.

regimes of high resilience: market prices are closer to the policy rate when trading costs and market depth revert more rapidly to their equilibrium levels. While the introduction of a new operational framework in March 2004 has increased the sensitivity of the EONIA spread to the speed of mean reversion in transaction costs, this has not significantly altered its sensitivity to the regime of depth resiliency. Finally, the increased frequency of interventions by the ECB over the first stage of the financial turmoil has essentially reduced the EONIA spread in the regime of low resiliency, without however altering its value in the highly-resilient regime. It could however be argued that the nature of the increased tensions observed in interbank markets over the first stage of the financial turmoil may require a note of caution on the latter findings. Indeed, widening market spreads as of August 2007 may a priori reflect changing perceptions of both liquidity and credit risks by market participants. In this case, an increase in the credit risk component of spreads could bias our results. Nevertheless, such a concern seems limited for the sample considered in this paper since spreads in the first stage of the financial crisis appear mostly sensitive to the liquidity risk component. Several elements support this view. First, the spread between the euro overnight rate and the euro overnight repo rate (secured against a more restrictive list of eligible collateral that that of the Eurosystem's refinancing operations) remained low and stable at an average of 6 bps until the collapse of Lehman Brothers. After September 2008, this spread increased markedly despite the unlimited provision of central bank reserves via the full allotment procedure of the ECB. Second, an examination of EURIBOR-/LIBOR-OIS spreads during the financial crisis also confirms the prominent role played by liquidity risk perceptions in the determination of the spread until September 2008 (see McAndrews, Sarkar and Wang (2008) or Sarkar (2009) for the US market or Schwarz (2010) in the European context). In the same vein, the evidence reported in Beirne (2012) suggests that credit risk does not significantly alter the EONIA spread before the collapse of Lehman Brothers. By contrast, this author shows that the sensitivity of the EONIA spread to liquidity risk increases significantly in the first stage of the financial crisis.

Given the specific structure of the overnight segment of the euro area money market (i.e., allowing banks to alternatively execute their overnight transactions through the electronic platform or over-the-counter), we also examine the absolute proportional deviation between the policy rate and the average price of the transactions executed by banks trading through electronic orders (i.e., the e-MID spread). This robustness analysis yields similar conclusions.[17] In summary, these findings thus appear insensitive to the type of orders, to the channel through which unsecured liquidity is provided, or to the characteristics of the bank trading in the market.

Against this background, we finally deem important to assess the sensitivity of the quality of order execution on the electronic platform to the resilience of spreads and depth in this market. When liquidity is strongly resilient, shocks to prices should be short-lived and disappear rapidly. This contrasts with weakly resilient liquidity conditions under which shocks are expected to last longer. As a consequence, strongly-resilient markets should improve the execution quality of interbank transactions.

Our proxy for execution quality is the absolute proportional deviation of electronic transaction prices from the euro overnight index average (EONIA). When the daily average price of the transactions executed through e-MID systems is close to the EONIA, the platform executes orders at prices on average similar to the price of the orders executed over-the-counter. The emergence of a gap between the two averages correspondingly points to a deterioration of execution quality on the electronic platform. In the specific context of the euro area, two additional elements support our benchmark. First, as the EONIA panel tracks the largest market participants, the volume traded by this panel is considered representative of the whole overnight segment of the money market. Second, the electronic platform attracts more market participants than the EONIA panel, including most small-sized banks. The absence of significant price differences with the EONIA would accordingly suggest that transacting on the platform is independent of the size of the banks, which we also interpret as a factor of execution quality.

Panel A of Table 9 reports the mean, median, and variance of the absolute proportional price deviation of electronic transactions from the EONIA. This Panel

[17]For space reasons, we do not report the results of this analysis in the paper. The results remain available upon request.

also provides test statistics of the null hypothesis of equal means, medians, and variances of the measure across regimes of spread and depth resiliency. All tests confirm that strongly-resilient liquidity conditions improve the execution quality of electronic orders. The absolute price deviation is significantly weaker (the mean and median are reduced) and less volatile (the variance of the measure is lower) when spreads and depth quickly revert to their long-term averages. Again, the picture is very similar across all spreads and depth proxies. An examination of the sensitivity of execution quality to resiliency regimes across our subsamples concludes our analysis. The evidence reported in Panel B of Table 9 supports the robustness of the above findings. Electronic orders are priced closer to the EONIA when the resilience of transaction costs or market depth is higher. Execution quality is interestingly not affected by an increase in market stress: our turmoil variable is never significant suggesting that the increased intervention of the central bank over the first stage of the financial turbulence has protected the dynamics of the different channels for the provision of liquidity to banks in the unsecured segment of the money market.

6 Concluding Remarks

In resilient markets, liquidity shocks are absorbed in a smooth way, without significantly affecting prices. When a shock occurs that drains liquidity from the market, participants become increasingly concerned with the ability of the market to restore liquidity. Weakly-resilient market conditions, under which liquidity shocks are absorbed very slowly, therefore hamper trading. When effective spreads (i.e., the cost of trading) deteriorate, transactions become more costly to execute. Widening effective spreads are thus likely to deter market players from trading in the market. Similarly, when liquidity shocks reduce the available market depth, traders may be more reluctant to transact. For these reasons, strongly-resilient markets with a strong ability to absorb liquidity shocks in a smooth way attract market players and hence favor trading.

Against this background and given the importance of the overnight money market in the provision of unsecured short-term funding to banks between the refinancing operations of the European Central Bank, we examine the speed of reversion of transaction costs and market depth to their long-term averages in this market over the period from 4 September 2000 to 31 December 2007.

This paper lends additional support to the limited literature on resiliency (see, e.g., Degryse et al. (2005) or Kempf et al. (2009)). Similar to the dynamics of order book liquidity at Paris Bourse documented in Degryse et al. (2005) and in spite of its specific design, depth appears more resilient than transaction costs in the overnight segment of the money market. Our Markov-switching mean reversion framework further highlights the nonlinear adjustment of market liquidity in this market. Spread and depth resiliencies are generally strong across our proxies and occasionally switch to a regime of weaker mean reversion. Resiliency regimes, as our analysis suggests, are significantly driven by liquidity, market activity, and the institutional setting of the market. The speed of mean reversion of our liquidity proxies is highly persistent across days. Low transaction costs improve the resilience of the tightness dimension of market liquidity. Deep markets similarly make depth more resilient to shocks. The reported evidence shows that the current design of the market guarantees the provision of unsecured funds to market participants even under unexpectedly active market conditions. Unexpected increases in market stress nevertheless tend to weaken the resilience of spreads. In addition to significantly affecting transaction costs and market depth, it also appears that the institutional setting drives the time dimension of market liquidity. Our analysis indeed shows that the introduction of structural changes in the implementation of the monetary policy in March 2004 has strengthened the resilience of liquidity in this market. However, spreads and depth are generally less resilient over the last days of the reserve maintenance period, during main refinancing operations, around the press conference and in particularly stressful market conditions (i.e., over the recent turmoil episode).

An examination of the sensitivity of the quality of this market to the resilience of liquidity concludes our analysis. Under regimes of high resilience, market spreads (i.e., spreads between the policy rate of the ECB and the average price of the transactions executed in this market) are significantly reduced and less volatile. Finally, the speed of mean reversion in transaction costs and market depth significantly affects the execution quality of the orders filled on the electronic platform: the absolute price deviation of electronic transactions from the EONIA is significantly weaker and less volatile when market liquidity converges quickly to its equilibrium level.

This paper contributes to the literature in microstructure in several ways. For the first time, we show that, despite the very specific features and nature of the overnight segment of the euro area money market, the temporal adjustments of liquidity in this market validate most theoretical predictions and lend further support to the empirical evidence observed mainly in stock markets (most notably, our findings are consistent with the evidence reported in Degryse et al. (2005) and Kempf et al. (2009)). Second, the influence of the institutional setting for the implementation of the monetary policy decisions on the speed of reversion of transaction costs and market depth to their long-run averages emerges as a distinguishing feature of this market. Third, despite a huge lack of confidence between market participants over the first stage of the financial turmoil that started in August 2007, the electronic platform has not broken down, still benefiting from the presence of patient traders, hence ensuring a continuation of trading albeit at a lower volume.

These empirical findings allow market participants and policymakers to gain further insight into the behaviour of banks and the provision of liquidity in the overnight money market, with a particular focus on the turmoil episode that shocked the money market in the euro area. More precisely, our results point to two particularly remarkable (and arguably new compared to other financial markets) developments. Although, as stress increases, some market participants switch to bilateral trading at the expense of the electronic platform (notably due to adverse selection reflecting the lack of confidence between market participants), others nevertheless renew their commitment to trade and provide liquidity in a more costly and volatile environment. However, the mistrust in the market and the increased sensitivity of information used to infer the financial position of banks have led market participants to avoid actions potentially damaging their reputation through negative signals. This has probably encouraged banks not to disclose their trading positions, and hence their depth, on such transparent systems as the electronic platform.

Appendix A Deseasonalisation

Gallant et al. (1992) set up the following three-step deseasonalisation technique (in their original notation):

Mean equation:

$$w = x'\beta + u$$

where x' is the set of variables that are assumed to cause the observed seasonality.

Variance equation:

$$log(u^2) = x'\gamma + \epsilon$$

Building on these equations, the adjusted (deseasonalised) measure is derived as:

$$w_{adj} = a + b(\hat{u}/exp(x'\gamma/2))$$

where the authors use values of a and b such that the unadjusted and adjusted measures both have the same mean and standard deviation.

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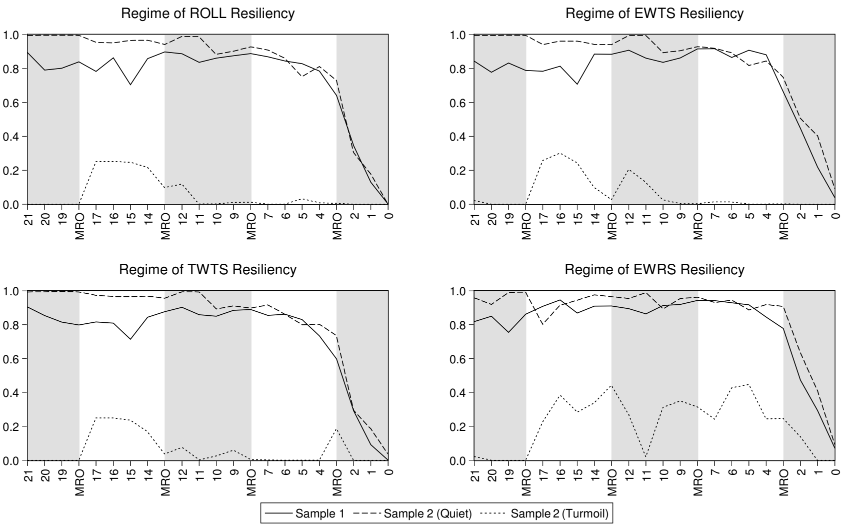

Figure 1: Spread resiliency regime probability. This Figure plots the probability of being in the high regime of spread resiliency over the reserve maintenance period. The horizontal axis shows the number of days remaining before the end of the period. MRO highlights the days on which main refinancing operations allotments take place. The shaded areas represent the days between the weekly operations of the central bank.

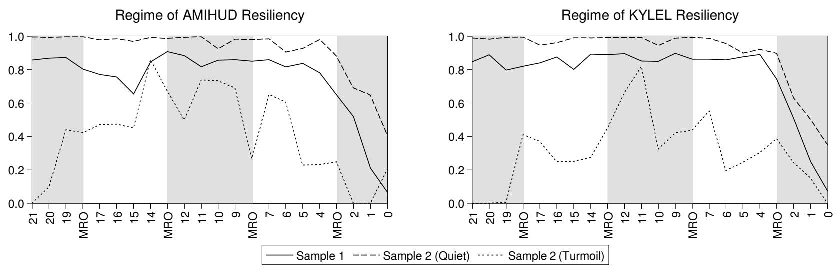

Figure 2: Depth resiliency regime probability. This Figure plots the probability of being in the high regime of depth resiliency over the reserve maintenance period. The horizontal axis shows the number of days remaining before the end of the period. MRO highlights the days on which main refinancing operations allotments take place. The shaded areas represent the days between the weekly operations of the central bank.

Table 1: Liquidity Proxies – Descriptive Statistics and Pairwise Correlations

Panel A – Descriptive Statistics

	Spread Proxies				Depth Proxies	
	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Mean	0.0227	0.0174	0.0172	0.0077	3.2995	127.3356
Std. Dev.	0.0299	0.0285	0.0232	0.0096	7.5815	230.7806
Median	0.0120	0.0088	0.0091	0.0050	0.9355	63.9176
Min.	0.0048	-0.0398	0.0018	-0.0094	0.0000	-1442.9351
Max.	0.2657	0.3751	0.2391	0.1217	82.1790	3314.8838

Panel B – Pairwise Correlations

	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
ROLL	1.0000					
EWTS	0.8334	1.0000				
TWTS	0.9200	0.8602	1.0000			
EWRS	0.8468	0.6947	0.7690	1.0000		
AMIHUD	0.7460	0.6860	0.7909	0.5774	1.0000	
KYLEL	0.7322	0.6311	0.7428	0.5991	0.6608	1.0000

This Table reports descriptive statistics and pairwise correlations for our liquidity proxies. ROLL is Roll's (1984) implicit effective spread; EWTS (resp. TWTS) is the equally-weighted (resp. time-weighted) average traded spread (Stoll 2000); EWRS is the equally-weighted realised spread (Huang and Stoll 1996); AMIHUD is Amihud's (2002) illiquidity ratio; KYLEL is the 5-minute Kyle's (1985) lambda. For the sake of clarity, AMIHUD and KYLEL are resized (multiplied by 1,000,000).

Table 2: Estimates of Spread and Depth Resiliency

Panel A – Resiliency Estimates

	Spread Proxies				Depth Proxies	
	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Overall						
β	0.3704***	0.3453***	0.3489***	0.2997***	0.6147***	0.5526***
t-statistic	(14.5716)	(11.4616)	(11.4526)	(11.1706)	(19.0099)	(15.3564)
Number of Lags	2	4	4	3	2	3
Observations	1870	1868	1868	1869	1870	1869
Wald Tests						
Spread equality	3.7979	$H_0 : \beta_{ROLL} = \beta_{EWTS} = \beta_{TWTS} = \beta_{EWRS}$				
Depth equality	1.6479	$H_0 : \beta_{AMIHUD} = \beta_{KYLEL}$				
Spread = depth	83.4362***	$H_0 : \beta_{ROLL} = \beta_{EWTS} = \beta_{TWTS} = \beta_{EWRS} = \beta_{AMIHUD} = \beta_{KYLEL}$				

Panel B – Resiliency Estimates across Samples

	Spread Proxies				Depth Proxies	
	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Sample 1						
β_1	0.5774***	0.6134***	0.5886***	0.5496***	0.6936***	0.5552***
t-statistic	(16.4259)	(13.8908)	(14.4533)	(14.6015)	(19.1601)	(13.7029)
Sample 2 (Quiet)						
β_{2Q}	0.6884***	0.7728***	0.7218***	0.6090***	0.8768***	0.6637***
t-statistic	(16.8011)	(14.2719)	(14.6358)	(12.7284)	(14.5641)	(11.6461)
Sample 2 (Turmoil)						
β_{2T}	0.2047***	0.2616***	0.2225***	0.1919***	0.3748***	0.5162***
t-statistic	(7.1598)	(8.5527)	(6.9118)	(6.7757)	(7.8786)	(10.9044)
Wald Tests						
$H_0 : \beta_1 = \beta_{2Q}$	8.4014***	11.5366***	10.9148***	2.2322	10.3158***	4.6028**
$H_0 : \beta_{2T} = \beta_{2Q}$	125.2814***	101.9058***	110.6858***	80.8277***	53.3294***	5.9916**
$H_0 : \beta_{2T} = \beta_1$	92.4060***	70.3569***	81.0253***	88.4415***	38.4512***	0.6472

This Table reports resiliency estimates across sub-samples. The overall sample period (i.e., from 4 September 2000 to 31 December 2007) is split into Sample 1 (from 4 September 2000 to 9 March 2004), Sample 2 – Quiet (from 10 March 2004 to 7 August 2007), and Sample 2 – Turmoil (from 8 August 2007 to 31 December 2007). Spread equality is a Wald test with $H_0 : \beta_{ROLL} = \beta_{EWTS} = \beta_{TWTS} = \beta_{EWRS}$. Depth equality is a Wald test with $H_0 : \beta_{AMIHUD} = \beta_{KYLEL}$. Spread and depth equality is a Wald test with $H_0 : \beta_{ROLL} = \beta_{EWTS} = \beta_{TWTS} = \beta_{EWRS} = \beta_{AMIHUD} = \beta_{KYLEL}$. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The significance of the mean reversion parameters is assessed by means of Dickey and Fuller's (1979) critical values.

Table 3: Regimes of Spread and Depth Resiliency

	Spread Proxies				Depth Proxies	
	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Regime 1						
β	0.9811***	0.9785***	0.9776***	0.7937***	0.9891***	0.9619***
t-statistic	(272.9982)	(256.3940)	(253.8940)	(59.5670)	(285.2753)	(104.0998)
Std. Error	0.0028	0.0029	0.0025	0.0016	0.8290	44.111
Observations	1335.8	1394.7	1340.0	1459.2	1489.7	1493.9
Probability	0.7131	0.7446	0.7153	0.7803	0.7957	0.7979
Duration	9.95	9.82	9.84	11.13	9.49	10.68
Regime 2						
β	0.4070***	0.4756***	0.4047***	0.4115***	0.5867***	0.8915***
t-statistic	(8.8192)	(9.1884)	(8.1122)	(6.3019)	(7.9373)	(14.8040)
Std. Error	0.0375	0.0418	0.0298	0.0146	12.573	397.68
Observations	536.2	477.3	532.0	409.8	382.3	378.1
Probability	0.2869	0.2554	0.2847	0.2197	0.2043	0.2021
Duration	4.01	3.37	3.91	3.14	2.44	2.71
LR linearity test	4422.1464***	4419.9048***	4062.4202***	3258.1924***	4847.0268***	3389.7757***
Lags	0	0	0	3	0	0
P_{11}	0.8995	0.8982	0.8983	0.9102	0.8946	0.9064
P_{22}	0.7504	0.7032	0.7446	0.6810	0.5895	0.6303

This Table reports mean reversion estimates in the high and low regimes of spread and depth resiliency. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The significance of our β coefficients is assessed by means of Dickey and Fuller's (1979) critical values. The significance of the likelihood ratio test of linearity is determined on the basis of Davies's (1977) upper bound.

Table 4: Deseasonalisation of Market Liquidity Proxies

Panel A – Mean Equation

	Spread Proxies				Depth Proxies	
	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Constant	0.0129***	0.0103***	0.0099***	0.0053***	1.9202***	83.0712***
	(15.2253)	(14.0404)	(15.7691)	(22.9613)	(8.0786)	(11.3700)
NF	−0.0041***	−0.0049***	−0.0036***	−0.0018***	−1.6781***	−35.5360***
	(-3.7682)	(-4.6074)	(-4.5808)	(-5.7077)	(-6.7157)	(-4.2371)
OF × Last Days	0.0411***	0.0304***	0.0333***	0.0106***	11.0998***	315.8480***
	(10.1668)	(8.5847)	(10.6374)	(7.1138)	(7.6941)	(7.7445)
NF × Last Days	0.0339***	0.0242***	0.0241***	0.0076***	4.9974***	142.4228***
	(9.6094)	(6.0350)	(8.9265)	(8.2032)	(6.3858)	(5.0518)
MRO Allotment	0.0112***	0.0091***	0.0082***	0.0032***	1.9595***	45.9861***
	(6.9275)	(5.1536)	(6.2733)	(5.2522)	(4.3548)	(2.9563)
OF × Press Conf.	0.0048	0.0021	0.0067**	0.0014	2.2222*	67.2105*
	(1.5245)	(0.9378)	(2.4511)	(1.4717)	(1.6670)	(1.7388)
NF × Press Conf.	−0.0220***	−0.0167***	−0.0168***	−0.0041***	−3.4435***	−106.6374***
	(-6.9514)	(-4.6497)	(-6.1964)	(-3.8159)	(-4.4554)	(-4.2719)
Turmoil	0.0583***	0.0574***	0.0445***	0.0197***	9.0942***	271.4251***
	(5.5181)	(5.4036)	(5.7264)	(5.2085)	(4.8674)	(4.4731)

Panel B – Variance Equation

	Spread Proxies				Depth Proxies	
	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Constant	−11.8759***	−11.9551***	−12.3932***	−13.8140***	−0.1479	7.1222***
	(-100.2619)	(-105.9480)	(-98.1008)	(-127.0487)	(-1.4831)	(71.5204)
NF	−0.5730***	−0.7378***	−0.6227***	−0.2810**	−2.0119***	−0.9823***
	(-3.3782)	(-4.5356)	(-4.0382)	(-1.9874)	(-14.8193)	(-7.6194)
OF × Last Days	4.1659***	3.7496***	−3.8561***	3.7912***	4.1381***	3.5418***
	(21.5728)	(17.3218)	(13.3305)	(17.5700)	(20.4929)	(18.4539)
NF × Last Days	4.0051***	3.4983***	3.4573***	2.7952***	4.0000***	2.8566***
	(19.0966)	(14.9713)	(14.5419)	(13.9272)	(19.4382)	(15.0358)
MRO Allotment	2.6149***	2.3899***	2.5406***	1.9308***	2.0835***	1.2650***
	(20.3600)	(17.5002)	(19.2618)	(16.4126)	(14.7472)	(9.8377)
OF × Press Conf.	1.6443***	0.6327	2.2304***	0.6116*	1.7129***	1.6344***
	(7.4323)	(1.5417)	(7.6692)	(1.8633)	(5.1136)	(6.3583)
NF × Press Conf.	−1.3214***	−1.4252***	−0.9472**	−0.5776	−1.8656***	−1.2739***
	(-4.5047)	(-4.1524)	(-2.5563)	(-1.6374)	(-6.2257)	(-4.0534)
Turmoil	4.0761***	4.8002***	4.4008***	3.9243***	4.8459***	3.4829***
	(9.7995)	(14.7598)	(12.2363)	(12.5997)	(14.9384)	(12.4160)

This Table reports the effect of the institutional setting on the mean (Panel A) and on the variance (Panel B) of our liquidity proxies. OF (resp. NF) is a dummy variable that takes the value 1 over the period from 4 September 2000 to 9 March 2004 (resp. 10 March 2004 to 31 December 2007), and is 0 otherwise. Last Days is a dummy variable that takes the value 1 between the last MRO allotment of a maintenance period and the very last open day of that period, and is 0 otherwise. MRO Allotment is a dummy variable equal to 1 on main refinancing operations allotment days, and is 0 otherwise. Press Conf. is a dummy variable that takes the value 1 for days on which decisions of the Governing Council of the ECB are communicated to the market, and is 0 otherwise. Turmoil is a dummy variable that takes the value 1 over the period from 8 August 2007 to 31 December 2007, and is 0 otherwise. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. t-statistics are reported in the parentheses. All tests rely on Newey and West's (1987) robust standard errors.

Table 5: Deseasonalisation of Market Activity Proxies

Panel A – Mean Equation

	NBTRD	EWQTY	RVOLA
Constant	482.8043^{***}	28.9253^{***}	-0.0005
	(97.7585)	(57.1652)	(-0.0694)
NF	-84.2979^{***}	22.4709^{***}	-0.0259^{***}
	(-14.1126)	(23.9400)	(-2.9101)
OF × Last Days	75.0887^{***}	-5.3717^{***}	0.3946^{***}
	(7.1858)	(-8.0016)	(6.6664)
NF × Last Days	47.5680^{***}	-4.8118^{***}	0.2943^{***}
	(8.1745)	(-4.3391)	(6.2618)
MRO Allotment	21.7467^{***}	-1.5473^{***}	0.1289^{***}
	(7.5740)	(-4.1651)	(5.2659)
OF × Press Conf.	6.2771	-1.4546^{**}	0.0487
	(0.8738)	(-2.3713)	(1.2484)
NF × Press Conf.	-38.6646^{***}	2.5831^{*}	-0.2339^{***}
	(-6.2039)	(1.8903)	(-6.0099)
Turmoil	-27.1107^{***}	-8.5934^{***}	0.4679^{***}
	(-2.8318)	(-4.5494)	(4.0867)

Panel B – Variance Equation

	NBTRD	EWQTY	RVOLA
Constant	6.8571^{***}	2.3989^{***}	-8.4010^{***}
	(52.9446)	(19.7305)	(-82.9773)
NF	-0.4643^{***}	1.1067^{***}	1.5286^{***}
	(-2.8557)	(7.2028)	(16.1705)
OF × Last Days	0.8815^{***}	-0.1022	5.6768^{***}
	(3.9476)	(-0.4673)	(34.0047)
NF × Last Days	0.3029	0.1134	3.0982^{***}
	(1.4669)	(0.6693)	(21.2974)
MRO Allotment	0.0542	-0.2661^{**}	2.8293^{***}
	(0.4059)	(-2.0775)	(22.8676)
OF × Press Conf.	-0.0830	-0.4894^{*}	1.8329^{***}
	(-0.2678)	(-1.7353)	(9.3116)
NF × Press Conf.	-0.2468	-0.4861	-4.0336^{***}
	(-0.7530)	(-1.3766)	(-9.4062)
Turmoil	-0.4283	-0.2988	3.8149^{***}
	(-1.4298)	(-1.2988)	(15.5635)

This Table reports the effect of the institutional setting on the mean (Panel A) and on the variance (Panel B) of our activity proxies. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. t-statistics are reported in the parentheses. All tests rely on Newey and West's (1987) robust standard errors.

Table 6: Determinants of Spread Resiliency Regimes

	ROLL		EWTS		TWTS		EWRS	
Depth Proxy	AMIHUD	KYLEL	AMIHUD	KYLEL	AMIHUD	KYLEL	AMIHUD	KYLEL
Constant	5.9728***	5.8240***	2.1911***	2.2648***	1.2793**	1.3685**	1.3185**	1.5270***
	(4.8736)	(4.7677)	(4.2358)	(4.4356)	(2.1940)	(2.3733)	(2.4596)	(2.9056)
Spread Regime_{t-1}	1.6474***	1.6224***	1.4604***	1.4685***	1.7013***	1.7010***	1.5165***	1.5039***
	(10.5912)	(10.3771)	(8.9968)	(9.1482)	(12.0134)	(12.0375)	(12.8816)	(12.4903)
Spread Regime_{t-2}			−0.6684***	−0.7300***				
			(-3.5731)	(-4.0017)				
Spread_t	−99.1740***	−109.6992***	−45.3452***	−46.9821***	−113.4332***	−109.1740***	−67.2960***	−61.8073***
	(-6.6970)	(-7.9833)	(-3.7703)	(-3.9025)	(-11.3344)	(-11.0282)	(-4.9574)	(-4.6952)
Depth_t	−0.0363	0.0006	−0.0486**	−0.0008**	0.0107	−0.0003	−0.0199**	−0.0015***
	(-1.4719)	(0.6546)	(-2.3346)	(-1.9648)	(0.7436)	(-0.6902)	(-2.0364)	(-3.9242)
NBTRD_t	−0.0003	0.0000	0.0006	0.0005	0.0015*	0.0014	−0.0008	−0.0008
	(-0.2343)	(0.0083)	(0.8628)	(0.6474)	(1.7080)	(1.5899)	(-0.9152)	(-0.9509)
EWQTY_t	−0.0057	−0.0024	0.0053	0.0057	0.0164***	0.0150***	0.0073*	0.0041
	(-0.9209)	(-0.4026)	(1.2656)	(1.3366)	(3.0890)	(2.8194)	(1.7304)	(0.9669)
RVOLA_t	−13.6326***	−13.8131***	−4.1431***	−3.9671***	1.5479**	1.5924**	−0.4636	−0.1649
	(-3.4586)	(-3.3727)	(-3.9673)	(-3.4445)	(1.9919)	(2.0819)	(-0.8457)	(-0.3444)
NF	2.0404***	2.0271***	1.1206***	1.0141***	1.1364***	1.1493***	0.2753*	0.2697*
	(7.1084)	(6.6345)	(5.4842)	(4.4102)	(4.0845)	(4.1238)	(1.9311)	(1.8407)
OF × Last Days	−7.7369***	−7.8134***	−3.5205***	−3.4641***	−3.8935***	−3.8758***	−2.4063***	−2.4251***
	(-5.9633)	(-5.7994)	(-10.4229)	(-10.1628)	(-10.8929)	(-10.9727)	(-13.0910)	(-13.7604)
NF × Last Days	−9.9733***	−10.0411***	−4.0577***	−3.8787***	−4.1159***	−4.1119***	−2.0539***	−2.0352***
	(-6.8001)	(-6.4797)	(-8.8495)	(-7.8942)	(-7.9244)	(-7.9064)	(-10.0154)	(-9.9582)
MRO Allotment	−6.1999***	−6.3027***	−2.3179***	−2.2182***	−1.5065***	−1.4927***	−0.5684***	−0.5223***
	(-5.0663)	(-4.9271)	(-6.8131)	(-6.4973)	(-4.2207)	(-4.2049)	(-3.7942)	(-3.4677)
OF × Press Conf.	−3.2746**	−3.3804**	−1.7675***	−1.7665***	−1.2795***	−1.2655***	−0.1089	−0.1269
	(-2.3369)	(-2.3169)	(-3.7675)	(-3.8126)	(-3.2967)	(-3.2948)	(-0.3779)	(-0.4155)
NF × Press Conf.	2.3262***	2.3297***	1.0111***	1.0152***	1.1983***	1.1808***	0.3420	0.3986
	(5.1801)	(5.0270)	(3.1926)	(3.2165)	(2.6851)	(2.6365)	(1.3010)	(1.5396)
Turmoil	−11.8304***	−11.9723***	−5.9909***	−5.7927***	−4.3403***	−4.3313***	−2.2507***	−2.2353***
	(-7.1267)	(-6.8164)	(-11.0679)	(-9.9106)	(-6.3469)	(-6.3184)	(-8.1129)	(-8.0384)
McFadden R^2	0.8573	0.8563	0.7364	0.7332	0.7928	0.7928	0.6176	0.6268

This Table reports the probit estimates of spread regime determinants. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. t-statistics are reported in the parentheses. All tests are based on Huber-White robust standard errors.

Table 7: Determinants of Depth Resiliency Regimes

	AMIHUD				KYLEL			
Spread Proxy	ROLL	EWTS	TWTS	EWRS	ROLL	EWTS	TWTS	EWRS
Constant	2.0362***	2.0410***	2.0937***	2.0129***	1.4559**	1.4443**	1.4638**	1.4837**
	(3.6749)	(3.6811)	(3.7793)	(3.6135)	(2.1641)	(2.1452)	(2.1733)	(2.2186)
Depth Regime$_{t-1}$	0.7876***	0.7794***	0.7754***	0.7894***	1.0935***	1.1019***	1.1028***	1.0953***
	(6.2712)	(6.3223)	(6.2404)	(6.3027)	(8.1115)	(8.2007)	(8.2298)	(8.2010)
Depth$_t$	−0.3084***	−0.3009***	−0.2977***	−0.3072***	−0.0056***	−0.0057***	−0.0056***	−0.0057***
	(-7.8912)	(-7.8631)	(-7.5711)	(-7.8710)	(-6.5957)	(-6.9034)	(-6.7289)	(-7.0278)
Spread$_t$	1.8721	−1.8516	−4.6471	5.5952	−3.4515	−2.2665	−3.1327	−4.5649
	(0.4622)	(-0.6328)	(-0.8903)	(0.6900)	(-0.8671)	(-0.9913)	(-0.9511)	(-0.5785)
NBTRD$_t$	−0.0011	−0.0010	−0.0011	−0.0011	−0.0004	−0.0004	−0.0004	−0.0004
	(-1.2608)	(-1.2114)	(-1.2684)	(-1.2635)	(-0.3988)	(-0.3986)	(-0.4198)	(-0.4484)
EWQTY$_t$	0.0060	0.0063	0.0062	0.0064	0.0124**	0.0122**	0.0119**	0.0120**
	(1.1339)	(1.1924)	(1.1785)	(1.2041)	(2.2633)	(2.2644)	(2.2310)	(2.2353)
RVOLA$_t$	−0.1330	0.0490	0.1595	−0.0951	−0.4506	−0.6162	−0.5883	−0.6555
	(-0.4284)	(0.2450)	(0.6023)	(-0.4500)	(-1.1038)	(-1.5414)	(-1.3675)	(-1.5279)
NF	2.7036***	2.7356***	2.7385***	2.7133***	1.2338***	1.2044***	1.2050***	1.1942***
	(4.5534)	(4.5686)	(4.5833)	(4.5777)	(5.0424)	(5.1844)	(5.1641)	(5.1973)
OF × Last Days	−2.4353***	−2.4239***	−2.4244***	−2.4295***	−2.3598***	−2.3763***	−2.3662***	−2.3767***
	(-11.4784)	(-11.5858)	(-11.5681)	(-11.5400)	(-11.0237)	(-11.4922)	(-11.3837)	(-11.5437)
NF × Last Days	−3.8743***	−3.8940***	−3.8892***	−3.8782***	−2.6567***	−2.6485***	−2.6372***	−2.6334***
	(-5.1526)	(-5.1425)	(-5.1534)	(-5.1499)	(-8.0579)	(-8.0573)	(-8.0421)	(-8.0387)
MRO Allotment	−0.9053***	−0.8973***	−0.8850***	−0.9011***	−0.5400***	−0.5465***	−0.5451***	−0.5514***
	(-4.7267)	(-4.7812)	(-4.6702)	(-4.7908)	(-3.0609)	(-3.1243)	(-3.1278)	(-3.1684)
OF × Press Conf.	−1.0720***	−1.0471***	−1.0490***	−1.0714***	−0.3941*	−0.3882*	−0.3948*	−0.4070*
	(-3.7705)	(-3.7614)	(-3.7434)	(-3.7936)	(-1.7260)	(-1.6954)	(-1.7349)	(-1.7863)
NF × Press Conf.	1.0577**	1.0432**	1.0313**	1.0500**	1.0733***	1.0759***	1.0738***	1.0817***
	(2.1777)	(2.1613)	(2.1397)	(2.1747)	(3.0827)	(3.1035)	(3.1225)	(3.1380)
Turmoil	−4.2691***	−4.2838***	−4.2821***	−4.2735***	−2.9910***	−2.9751***	−2.9641***	−2.9681***
	(-5.2006)	(-5.1874)	(-5.1975)	(-5.1973)	(-7.7277)	(-7.7454)	(-7.7289)	(-7.7237)
McFadden R^2	0.6793	0.6794	0.6796	0.6794	0.6792	0.6792	0.6791	0.6789

This Table reports the probit estimates of depth regime determinants. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. t-statistics are reported in the parentheses. All tests are based on Huber-White robust standard errors.

Table 8: Market Quality, Resiliency Regimes, and the Operational Changes

Panel A – EONIA Spread across Resiliency Regimes

	Spread Proxies				Depth Proxies	
Regime	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Mean						
High Resilience	0.0240	0.0255	0.0248	0.0251	0.0263	0.0255
Low Resilience	0.0553	0.0548	0.0583	0.0616	0.0599	0.0647
Welch F-test	130.6992***	94.7141***	106.7025***	110.3363***	88.4076***	109.6079***
Standard Deviation						
High Resilience	0.0134	0.0182	0.0145	0.0171	0.0214	0.0190
Low Resilience	0.0617	0.0633	0.0627	0.0675	0.0665	0.0686
Brown-Forsythe	373.9351***	311.6703***	348.3482***	399.7663***	311.1237***	406.2932***
Median						
High Resilience	0.0214	0.0217	0.0216	0.0215	0.0216	0.0215
Low Resilience	0.0343	0.0326	0.0323	0.0378	0.0378	0.0409
van der Waerden	128.3538***	79.4468***	78.8280***	134.1817***	105.3687***	149.3965***

Panel B – EONIA Spread, Resiliency Regimes, and the Operational Changes

	Spread Proxies				Depth Proxies	
Regime	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Constant	0.0287***	0.0295***	0.0283***	0.0313***	0.0429***	0.0436***
	(6.1781)	(5.7344)	(5.8508)	(6.7604)	(4.8252)	(5.6130)
OF	0.0198***	0.0162***	0.0164***	0.0239***	−0.0022	0.0068
	(3.3977)	(2.5980)	(2.7228)	(3.4457)	(-0.2444)	(0.8022)
Turmoil	−0.0114**	−0.0129**	−0.0113**	−0.0119**	−0.0209**	−0.0244***
	(-2.2786)	(-2.4321)	(-2.2095)	(-2.3548)	(-2.4239)	(-3.0530)
High Resilience	−0.0140***	−0.0151***	−0.0141***	−0.0157***	−0.0290***	−0.0293***
	(-3.1545)	(-3.1659)	(-3.0930)	(-3.8536)	(-3.4030)	(-3.9633)
OF × High Resilience	−0.0271***	−0.0222***	−0.0231***	−0.0297***	−0.0027	−0.0118
	(-4.3736)	(-3.3864)	(-3.6254)	(-4.1661)	(-0.2887)	(-1.3431)
Turmoil × High Resilience	−0.0018	0.0031	−0.0004	0.0031	0.0126	0.0204**
	(-0.2936)	(0.4235)	(-0.0777)	(0.5882)	(1.4117)	(2.3878)
EONIA Spread$_{t-1}$	0.4551***	0.4777***	0.4773***	0.4445***	0.4972***	0.4670***
	(10.8453)	(10.5870)	(11.0768)	(9.9498)	(10.2682)	(9.5415)
Adjusted R^2	0.4109	0.3875	0.3942	0.4053	0.3815	0.4108

This Table reports the EONIA spread across resiliency regimes and following changes to the operational framework for the implementation of the monetary policy. The EONIA spread is the absolute proportional spread between the prevailing ECB policy rate and the average trade price of the largest market participants. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. t-statistics are reported in the parentheses and are based on Newey and West's (1987) robust standard errors.

Table 9: Execution Quality, Resiliency Regimes, and the Operational Changes

Panel A – Electronic Trades vs. the EONIA across Resiliency Regimes

	Spread Proxies				Depth Proxies	
Regime	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Mean						
High Resilience	0.0019	0.0020	0.0019	0.0021	0.0022	0.0022
Low Resilience	0.0074	0.0078	0.0073	0.0084	0.0086	0.0089
Welch F-test	182.3540***	160.8156***	166.3462***	146.6322***	145.2618***	145.1443***
Standard Deviation						
High Resilience	0.0015	0.0018	0.0018	0.0023	0.0028	0.0026
Low Resilience	0.0093	0.0097	0.0093	0.0100	0.0100	0.0102
Brown-Forsythe	397.4756***	391.4293***	356.8770***	411.5148***	394.8372***	403.1872***
Median						
High Resilience	0.0016	0.0017	0.0016	0.0017	0.0017	0.0017
Low Resilience	0.0040	0.0041	0.0039	0.0046	0.0048	0.0053
van der Waerden	310.0958***	302.5492***	291.5412***	284.8930***	296.3069***	319.7861***

Panel B – Electronic Trades vs. the EONIA, Resiliency Regimes, and the Operational Changes

	Spread Proxies				Depth Proxies	
Regime	ROLL	EWTS	TWTS	EWRS	AMIHUD	KYLEL
Constant	0.0051***	0.0056***	0.0050***	0.0059***	0.0083***	0.0076***
	(7.6799)	(6.8606)	(7.0392)	(7.0846)	(6.8549)	(7.2897)
OF	0.0032***	0.0029***	0.0028***	0.0037***	−0.0010	0.0011
	(3.4384)	(2.6985)	(2.9859)	(3.1314)	(-0.7175)	(0.8599)
Turmoil	0.0006	0.0001	0.0007	0.0003	−0.0004	−0.0009
	(0.5342)	(0.1192)	(0.5582)	(0.2503)	(-0.2390)	(-0.5829)
High Resilience	−0.0039***	−0.0043***	−0.0038***	−0.0045***	−0.0070***	−0.0062***
	(-5.9574)	(-5.2803)	(-5.3425)	(-5.4968)	(-5.7474)	(-6.0283)
OF × High Resilience	−0.0026***	−0.0023**	−0.0023**	−0.0029**	0.0017	−0.0003
	(-2.7555)	(-2.1122)	(-2.3527)	(-2.4230)	(1.2209)	(-0.2523)
Turmoil × High Resilience	0.0007	0.0007	0.0004	0.0020	0.0007	0.0028*
	(0.5416)	(0.4862)	(0.3381)	(1.1491)	(0.4497)	(1.8331)
Spread_{t-1}	0.1490***	0.1522***	0.1641***	0.1144***	0.1678***	0.1448***
	(4.5825)	(4.6378)	(5.1308)	(3.1482)	(5.0873)	(4.7903)
Adjusted R^2	0.2411	0.2384	0.2267	0.2431	0.2337	0.2433

This Table reports the absolute proportional spread between the price of electronic trades and the EONIA across resiliency regimes and following changes to the operational framework for the implementation of the monetary policy. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. t-statistics are reported in the parentheses and are based on Newey and West's (1987) robust standard errors.