Repo Market Microstructure in Unusual Monetary Policy Conditions

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Abstract[1]

The financial turmoil that began in mid-2007 produced severe stress in interbank markets and prompted significant changes in central banks' funding operations. We examine the changing characteristics of ECB official interventions through the crisis and assess how they affected the efficiency and reliability of the secondary repo market as a mechanism for the distribution of interbank funding. The limit orderbook from the BrokerTec electronic repo trading platform is reconstructed to provide a range of indicators of participating banks' aversion to the risk of failing to fund their liquidity needs. These indicators anticipate similar variables from ECB reverse repo auctions and are also affected by surprise outcomes of auctions.

Keywords: Repo, Financial crisis, liquidity, market microstructure, monetary policy operations.

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1. Introduction

The ECB reacted to the financial turmoil of 2007-2009 with unprecedented policies aimed at ensuring that solvent banks could continue to satisfy their liquidity requirements when interbank sources contracted. How exactly did events in the interbank market affect the conduct of official operations, and did anticipated changes in official interventions have spill-over effects to liquidity provision in secondary interbank repo markets? We address these issues through a detailed analysis of ECB interventions and by an analysis of the microstructure of the electronic secondary repo market in the euro-area throughout the financial turmoil. The analysis shows that crisis-related liquidity shocks had a significant effect on the functioning of the secondary repo market both in anticipation of policy initiatives and in reaction to policy surprises.[2]

An important feature of the secondary repo market is the fact that many of the participants also have privileged access to ECB official operations. This means that official operations are potentially a direct substitute for interbank activity. It is clear that the rate obtained in official operations (or the expected rate) directly affects the rate that banks are willing to pay or accept in the secondary market. Indeed, affecting interest rates in the interbank market is precisely the objective of such operations. However, in the context of a liquidity crisis, anticipated provision of liquidity in official operations and the uncertainty surrounding such interventions is likely to have had profound effects not just on the rate available in the secondary market but, more importantly, on the amount of liquidity provided and obtained there.

The ECB's Financial Stability Review (2009) makes an important distinction between the market's ability to redistribute liquidity across banks experiencing idiosyncratic shocks and how the market copes with sudden, large, aggregate liquidity shocks. Official interventions are designed to cope with the common shocks and the secondary market normally copes well with the redistribution necessary to deal with idiosyncratic shocks. During the recent crisis there were larger than normal policy actions and these were conducted under increased uncertainty about general liquidity conditions. It is therefore likely that some operations led to substantial aggregate shocks.

[2] This confirms and adds to the findings described in Hördahl and King (2008).

The ECB has been aware of the potential impact of its unusual operations on the secondary market but to our knowledge most of these effects have not be explored in detail. In a speech by a member of the executive board of the ECB, José Manuel González-Páramo in Madrid on 16th Jan 2009, it was stated that,

> "…as long as money markets remain dysfunctional, it is crucial for the Eurosystem to continue to provide as much liquidity as needed in order to ease tensions in the impaired money markets, with a view to ensuring that access to liquidity of solvent banks is not disrupted, thereby also contributing to safeguarding financial stability. However, this is not the ideal long term solution in a market oriented economy like the euro area. It may discourage the resumption of normal interbank trading activity. It also potentially implies increased financial risks for the Eurosystem."

While it is clear that the increasing substitutability of official sources of liquidity for interbank sources is an important determinant of the microstructural characteristics of the secondary repo market during the crisis, some of these effects could have improved liquidity in the secondary repo market. Since some participants in the secondary market do not have access to ECB operations it is possible that the secondary repo market remained important as a redistributive mechanism. Also, since the unsecured interbank market was badly affected by counterparty risk there may have been a substitution effect that favoured increased liquidity of the repo market.

Evidence (but not causal attribution) has been provided of the virtual collapse of the repo market at the most severe moments of the recent crisis. Hördahl and King (2008) found that, as the financial market turmoil intensified throughout 2008, repo transactions (i) became restricted to shorter maturities (ii) involved higher quality collateral and (iii), in the case of general collateral repos, were done at reduced spreads relative to overnight index swap (OIS) rates. These changes may have reflected concerns about the credit worthiness of counterparties, the increasing demand for liquid assets and the hoarding of high quality collateral. Supply and demand factors are suggested to be linked to the behavior of money market funds that increasingly retained their liquid assets and to the behavior of longer-term investment funds that were increasingly reluctant to lend out high quality assets.

While counterparty risk has been identified in the existing literature as a causal factor in the crisis it is difficult to see how this could have been a ***direct*** cause of significant changes to the microstructure of the repo market. In the case of the secondary repo market, most European

repo contracts are cleared through LCH Clearnet Ltd which assumes the counterparty risk.[3] However, it is plausible to suggest that causality may have run *indirectly*. When the unsecured interbank market collapsed, expectations of more favorable (perhaps less risky) and more generous official supply of liquidity may have constrained supply of liquidity from banks to each other in the secured lending market. Our analysis throws some light on this potential chain of causality.

Since banks were willing to bid aggressively in excess of the target/policy rate at pivotal times during the crisis to ensure that they obtained sufficient liquidity, this begs the questions; did bidding aggressiveness in official operations simply reflect aggressive seeking of yield for funds, and unusual imbalance in liquidity provision in the secondary repo market, or did anticipated supply of liquidity in official operations help to cause such conditions? If the anticipated supply at favorable rates (with zero counterparty risk) caused agents not to participate in the secondary market in advance of auctions, this provides a self fulfilling outcome from the policy action and it is important to quantify these effects so that renormalization can be facilitated. The likelihood that anticipated supply drove out interbank intermediation was probably greatest in the last phase of the crisis which was characterized by official auctions seeking to fulfill all bids at the policy rate. While it is clear that unanticipated outcomes from official auctions could be disruptive for the secondary market (as described in Brunetti, Filippo and Harris 2009 for the case of the unsecured interbank market), it is also possible that anticipated over-provision of liquidity in official operations could cause pre-emptive contraction in liquidity provision in secondary markets and this deserves further analysis by direct examination of secondary market data.

Our analysis concerns the relationship between indicators of *funding liquidity risk aversion* in official operations and the equivalent measures from the secondary repo market. We examine a pre-crisis period for comparative purposes. We then identify two different phases of the crisis in order to distinguish between periods that were characterized by normal auction procedures

[3] According to the Clearnet web site, http://www.lchclearnet.com/fixed_income/repoclear/how_it_works.asp ATS trades are registered with RepoClear when they are agreed on the screen and on receipt and confirmation of 'eligible transactions' the counterparty risk is assumed by LCH Clearnet. Eligibility mostly concerns the checking of whether the counterparty is a member of the Clearnet counterparty list. All countries considered in our analysis except Greece are covered in this way. In the case of Greek data we only consider the special contract and it is difficult to distinguish between the effects of counterparty risk and specialness.

and a phase when there was no uncertainty about the rate that would prevail in auctions, but in which the quantity allotted remained highly uncertain (i.e., in the case of 'fixed-rate full-allotment' auctions).

Drehmann and Nikolaou (2010) use the aggressiveness of bidding behaviour of banks in Main Refinancing Operations (MROs) as an indication of their "funding liquidity risk aversion". This provides us with a useful indicator of secured interbank market stress related to the aggressiveness of banks' bidding behavior in official operations. The deviation between the intended policy rate and the weighted average rate obtained by participants in official operations is indicative of variation in liquidity needs not satisfied in the interbank market.[4] However, in the last phase of the crisis (with full-allotment auctions) the Drehmann and Nikolaou indicator is not available. This does not rule out the use of other indicators of liquidity risk aversion from auction results (such as surprises in the amounts bid in auctions) but we leave this for future work. Our heuristic examination of the data for the period of full-allotment auctions does however indicate reduced interbank market stress and possibly excessive supply of liquidity in official interventions relative to what is traded among the bank.

Our analysis follows in the same vein as a number of studies concerned with repo operations of the ECB. In Nyborg et al. (2002) the weekly repo auctions of the ECB are examined to gain an understanding of how bidding strategies affect the outcomes. Eisenschmidt et al (2009) examine bidding behavior in ECB funding operations during the crisis and find that it was affected by the increased individual refinancing motive, the increased attractiveness of the ECB's tender operations due to its collateral framework and banks' bidding more aggressively, i.e. at higher rates, to avoid being rationed at the marginal rate in times of increased liquidity uncertainty.

Section 2 discusses the context within which our analysis is conducted. We outline how counterparty risk manifested itself during the crisis and we identify periods when the secondary repo market was affected by counterparty risk despite the collateralized nature of such transactions. We then discuss the policy reaction in terms of interest rate setting and regular

[4] Although Drehmann and Nikolaou (2009) develop a more accurate measure based on the individual bidding behaviour they regard the gap between the target rate and the weighted average rate obtained in auctions as a good substitute for 'funding liquidity risk aversion'. This has the advantage of being publicly available soon after auctions.

(as well as irregular) refinancing operations. Our analysis of the refinancing operations reveal that at pivotal times during the crisis the ECB's refinancing target rate was often greatly exceeded and that the percentage of auction participants who obtained the marginal rate declined markedly. Also, the number of bidders participating in auctions, the unsatisfied demand in such auctions and the rates obtained by some participants, provides insights about how effectively ECB operations helped to counter dysfunction of the interbank market due to the counterparty risk problem. In Section 3 the main characteristics of the secondary repo market in Europe are described. This is based on information from SIFMA surveys of market participants which gives an indication of the size of the secondary repo market (including OTC trading) and the proportion that is traded electronically. We describe in detail the BrokerTec electronic market for European repos. With this general background we proceed to a more detailed analysis of the microstructure characteristics of the BrokerTec repo market data during the crisis and around policy events.

Section 4 addresses the econometric methodology we employ to identify the spill-over effects of the crisis and the effects of policy interventions on the secondary repo market. We adapt the basic approach of Andersen et al. (2002) to suit both anticipation of outcomes and reaction to policy events. This has direct parallels with recent research on the unsecured interbank market stress during the crisis. In Brunetti, Filippo and Harris (2009) the effect of official interventions on the unsecured, electronic, interbank lending market is analyzed. They conclude that large ECB policy initiatives during the crisis increased the level of uncertainty in the interbank market and crowded out private provision of liquidity. We analyze the post auction effects on liquidity in the secondary repo market but our analysis also considers the effects pre-auction effects of anticipated liquidity provision from official operations. Despite the relatively small number of events analysed, the richness of our dataset affords us the opportunity to obtain estimates of the effects of anticipated policy actions. The results and interpretation of the results is contained in Section 5.

2. Funding Operations and Counterparty Risk

The mechanisms by which official interventions are managed in the euro-area and the US have important differences. The ECB operates through secured lending operations with direct participation from banking institutions all over Europe. This broad participation is helpful in terms of securing liquidity distribution (and short term funding supply) across a large number of

banking institutions. The only impediment to access to such funding is capital adequacy and the availability of adequate collateral to take advantage of refinancing operations. These constraints were not initially problematic during the crisis. It was thus easy for the ECB to step-up its operations and become a major intermediary, virtually replacing interbank activity. While the interbank market may have been abruptly supplanted as a source of funding, the step-up in ECB activity may also have led to an increased need for the services of a redistribution facility such as the secondary repo market to get ECB funding to institutions with the most serious liquidity and funding needs. Since unsecured funding markets were badly affected by the crisis due to elevated counterparty risk, the secondary repo market increased in importance but the specific effects of official intervention on this market remain unknown. It is indeed possible that official interventions have had more structural impact on the repo market in Europe than in the US simply because so many banks have access to official funding operations in the former. Since a good distribution of funding across a wide variety of participants is achieved through ECB operations directly, it might also be concluded that an additional distributive mechanism such as the secondary repo market is less necessary than in the US where only primary dealers have access to the official repo lending facilities.

Our study considers the effects of policy events in the European context in three phases. The pre-crisis phase runs from 2nd Jan 2006 to 8th Aug 2007 and is characterized by normal repo operations and an upward trend in interest rates. In this phase there are 19 reserve maintenance periods and 19 ECB interest rate decision dates. On 7 of these dates interest rates were raised. On the remaining 12 occasions interest rates were left unchanged. The second phase (8th Aug 2007 – 2nd Oct 2008) is the first crisis phase and this was mostly characterized by stable, but relatively high official rates. There are 14 maintenance periods and therefore 14 ECB interest rate decision dates in this phase. There was only one interest rate change, which was positive. This phase includes the Lehman collapse which produced extreme volatility and interbank market stress. The last phase (3rd Oct 2008 – 31st Mar 2009) begins just before the "General Announcement on Liquidity Policy" by the ECB on 8th Oct 2008 which introduced the 'fixed-rate' 'full-allotment' auction policy. This phase is characterized by declining rates with 6 reductions in the reference interest rate out of a possible 7 decision dates.

The two phases covering the crisis involve two different approaches by the ECB to mitigate the effects of the financial turmoil. In the first crisis phase the ECB modified its funding procedures by (1) adjusting the distribution of liquidity over the reserve maintenance period by

systematically allotting liquidity in excess of the theoretical 'benchmark allotment' (front-loaded near the early part of the maintenance period) while still aiming for balanced liquidity conditions at the end of the maintenance periods (we note below that while there was increased supply there was also increased excess demand), (2) extending the average maturity of its financing, and (3), engaging with other central banks to relieve liquidity shortages of the euro-area banks in other currencies (mostly US dollars as part of the TAF operations). In the second crisis phase, in addition to aggressive reductions in the targeted refinancing rate, the ECB (1), introduced a fixed rate tender procedure with full allotment in both the main refinancing operations and the long-term refinancing operations, (2) increased the number of longer term operations,[5] (3) increased the range of assets eligible for use as collateral in Eurosystem credit operations[6] and (4) increased US dollar swap financing by use of fixed-rate tenders with full allotment by special arrangements with the Federal Reserve System. On 7th May 2009 the ECB also announced that it would begin operations to buy EUR 60 billion of covered bonds and that the European Investment Bank (EIB) would become an eligible counterparty in Eurosystem's monetary policy operations on 8th July 2009. Some effort was made (effective 21st Jan 2009) to encourage banks to re-engage with each other in the unsecured interbank market by re-widening the corridor between rates for standing facilities to 200 basis points around the rate on main refinancing operations (the 100 bps corridor had been introduced in Oct 9th 2007).

The fixed rate full-allotment policy of the ECB was announced on 8th Oct 2008 and came into effect on 15th Oct 2008 and it placed a virtual **cap** on the secondary market repo rate. In normal circumstances the ECB tries to ensure that banks have access to short term liquidity facilities purely to avoid unanticipated, temporary shortfalls in their requirements. Under such normal circumstances ECB funding was rationed in a competitive setting, and the repo rate was driven to a level that would be of only marginal benefit to banks facing unexpected liquidity shortages. Figure [1] shows that the introduction of fixed-rate full allotment auctions appears to have driven yields in the secondary market below the ECB policy target rate.

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[5] The ECB introduced three additional operations per month (two with three month term and one with six month term) and an additional operation with term corresponding to the reserve maintenance period.

[6] The list of eligible was expanded on 15th October 2008 and in May 2009 this policy was prolonged until end-2010.

In the euro-area, refinancing operations of the ECB in the pre-turbulence period were very stable with around 300 billion EUR outstanding in weekly refinancing of liquidity provision on an on-going basis. The supply in MRO auctions was roughly equal to what was maturing from the previous week's operation. Likewise, in the pre-turbulence period, Longer Term Operations were stable and usually involved outstanding repo lending by the ECB of about 100 billion EUR (also planned to replace maturing operations). Significant changes occurred in the last quarter of 2008 reflecting the ECBs efforts to relieve tensions in the short term refinancing markets through increased volume and terms of their operations. MROs declined to achieve about 150 million EUR outstanding and this facilitated an increase in the supplementary longer terms operations. SLTROs were of increasingly longer duration and new supply in these operations was more than replacing what was maturing from previous operations. In the second phase of the crisis (associated with fixed-rate, full-allotment auctions) the outstanding issued amount from SLTROs increased markedly and this was not related to reduction in either standard LTROs or MROs. At its peak, the outstanding financing (including operations of weekly duration and longer term and special supplementary operations) amounted to roughly 900 billion EUR. Figure [2] shows the outstanding funding associated with LTRO and Supplementary LTROs over the sample period.

The SLTROs were deliberately targeted at relieving the need for banks to provide both unsecured and secured funding to each other. There is a large difference between how this was done in the two phases of the crisis. In the first phase of the crisis the policy rate (which was normally consistent with the marginal yield settled at auctions) became less indicative of yields settled for average bidders. The method for allocating supply was still on the basis of discriminatory auctions and since demand was greater than usual, and bidding was more aggressive, the settlement rate diverged from the policy rate. More risk averse bidders were often allocated supply at rates that significantly exceeded the policy rate.

From 2nd Jan 2006 to 31st Mar 2009 there were 168 main refinancing operations (MROs), 38 normal long term refinancing operations (LTROs), 55 fine-tuning operations (OTs) and 26 supplementary (crisis-related) long-term refinancing operations (SLTROs). The first of the supplementary operations took place on Friday 24th August 2007. The breakdown of operations by type and phase is shown in Table [1]. Before we relate surprises from policy variables to repo market microstructure it is important to have a clear understanding of trends and structural breaks that are directly apparent from an examination of the time series of outcomes from the

auctions. We now discuss a number of relevant post-auction variables with this intention. We begin with the number of bidders in auctions which is displayed in Figure [3] for the case of MROs. The number of bidders rises dramatically in the immediate aftermath of the Lehman collapse when counterparty risk was most acute. At its height the number of bidders was twice its normal level. We found the same pattern in other types of operations. In pre-crisis LTROs the number of bidders was around 175 and at the height of the crisis this rose to 250. There were slightly fewer participants in the SLTROs that began in the first phase of the crisis but this also rose to about 225 at the height of the crisis.

Most of the SLTROs had a maturity of 3 months however there were 8 that had a maturity of six months. Thus the increased supply of this longer-term maturity would have reduced the need for a normal supply at the weekly MROs. In the announcement that accompanied the first supplementary auction it was stated that "the allotment amounts in the main refinancing operations will offset this provision of liquidity, taking into consideration the overall liquidity conditions." There was some reduction in amounts issued in MROs but Figure [4] shows that taking into account the longer average duration of the supplementary operations, outstanding issuance rose significantly (in the full-allotment period it obviously increased to match liquidity demanded).

It is difficult to assess whether the amounts supplied was in fact sufficient unless one also considers amounts demanded. Figure [5] shows demand and supply in each of the four main types of operations together. It should be noted that the supply and demand are equal in most of the last phase since this was the period of the fixed-rate full-allotment auctions where demand was completely satisfied. This led to a significant jump in the actual supply. When supply and demand are not equated we see that demand virtually always outstrips supply. It is useful to know that this was also the norm in the pre-crisis period.

The most revealing information from auctions can be obtained by examining the marginal rate and weighted average rate obtained at auctions. Before the introduction of fixed rate full allotment on 8th October 2008 auctions were settled at discriminating rates. Participants more desperate to ensure supply at auctions bid at higher rates than the best rate obtained (this is described in Drehmann and Nikolaou, 2010). Attainment of the refinancing rate that is announced at ECB interest rate meetings is a significant mechanism by which ECB policy is achieved. In Figures [6] and [7] we consider the two ways in which auction rates relate to intended rates. In Figure [6] we show the difference between the Marginal Rate attained in

MRO auctions as a deviation from the most recently announced refinancing rate. We label this the Target Gap. The gap widens at points of acute stress during the crisis (we include the EONIA-OIS spread in Figure [6] to make this clear). It seems that as participants were increasingly desperate to ensure supply at auctions they bid for more supply than the ECB was prepared to supply at rates that exceeded the target rate and this forced settlement at a marginal rate that was sometimes significantly above the official target.

Thus we have two outcomes from the auction that matter for liquidity. One is the fact that quantity was constrained relative to what would have satisfied demand at the official target rate and the other is the fact that the price of liquidity (i.e., the rate) exceeded what was intended. The second effect was actually more serious than is revealed by the deviation between the target rate and the marginal rate obtained. Figure [7] shows the weighted average rate obtained in MROs auctions in excess of the marginal rate obtained (as just described, the marginal rate itself deviated from the target rate at points of stress). We call the spread between the marginal rate and the weighted average rate the AWAYRATE. We include in Figure [7] the EONIA-OIS spread which was shown earlier and represents the degree of counterparty risk associated with unsecured interbank lending. The AWAYRATE has a high correlation with the EONIA-OIS spread. The fact that there was both unsatisfied demand and a higher rate than officially desired in auctions in this period, implies that official funding operations may have contributed to liquidity stress. For now, we are content to conclude that the two series are simply contemporaneously correlated and we do not infer the direction of causality. However, on the basis of the target gap, ECB operations do not appear overly generous in satisfying liquidity needs. According to Drehmann and Nikolaou this gap simply reflects the increased risk aversion to 'funding liquidity risk' on behalf of auction participants. The foregoing analysis of ECB operations provides an important backdrop to our analysis below.

Repo rates and counterparty risk?

It is widely believed that the recent financial market crisis had most of its effects in the form of elevated counterparty risk and stress in the **unsecured** interbank lending markets. This has often been described using the LIBOR-OIS spread (in the European context the EONIA-OIS spread). Swap interest rate deals are settled on the basis of the profit or loss made on the fixed rate that is swapped for the floating rate so there is only netting-off risk. This is usually very small relative to amounts that are traded in the alternative unsecured lending market and so

the difference between these rates mainly reflects interbank counterparty risk. The repo market involves secured lending and it is therefore also regarded as largely free of counterparty risk. Figure [8] shows the EONIA-Eurepo spread during the period we study along with the EONIA-OIS spread. It is clear from this that repo rates moved almost in step with swap rates and this would seem to confirm that the repo market did not suffer significantly from the effects of elevated counterparty risk during the crisis. However, there were periods in which even the repo rate seemed to reflect the effects of counterparty risk (or alternatively, the effects of the hoarding of high quality collateral).

Figure [9] shows the difference between the Eurepo and EONIA Swap rates in order to reveal this small but significant difference. This provides some evidence that the repo market suffered either directly or indirectly from elevated counterparty risk during the crisis but to far less an extent than the unsecured interbank market. Even when the premium is significantly different from zero it remains about one-tenth of the size of the EONIA-OIS spread. This small premium could be related to the presence of risks of non-delivery of collateral (or funds) as described by Heider, Hoerova and Holthausen (2009). However, non-delivery is not a significant risk for transactions undertaken on the BTEC automated trading system (ATS) since the counterparty risk is assumed by the central clearer, LCH Clearnet Ltd. While it is possible that the remaining premium reflects a small but significant probability of a failure of the Clearnet system itself, we regard it as more likely that counterparty risk infected the secondary repo market indirectly. This arises through the anticipation of changes in liquidity providing operations by the ECB following shocks to counterparty risk in other parts of the interbank system. For example, if repo market participants become aware of sharp changes in counterparty risk in the unsecured interbank market this may lead to expectations of liquidity easing by the ECB in its forthcoming operations. This in turn can be expected to affect liquidity provision in the secondary interbank repo market because participants may decide to wait for better rates on offer in official operations. In this case the repo rate available in the interbank repo market would reflect some counterparty risk or at least anticipate the rate that is going to be available in ECB operations.

3. Repo Markets and Repo Market Indicators of Funding Liquidity Risk

Construction of Indicators from Official Operations

In the case of all operations, information was gathered about the announcement of the operation and the reported outcome of the operation. This information was gathered from the ECB website and from news releases on Bloomberg. The exact time of news releases was recorded. In addition to the excess yield over the policy rate (and the excess of the weighted average yield over the policy rate), surprises in the amount issued and demanded relative to amounts maturing or announced as 'intended' are the focus of our empirical examination. In the last phase (the fixed-rate full-allotment period) we also consider the change in the outstanding supply as an important variable (this is different from other studies where the surprise supply is based on the difference between what was announced as the intended supply and what was actually allocated). The reason we consider this new indicator of surprise supply is because intended supply in the past was usually related to expected amounts maturing from previous operations but during the last phase of the crisis intended supply did not relate strongly with amounts maturing from previous operations. Clearly, when supply (amount outstanding) is increasing significantly more than is apparent from the supply in excess of announced "intended supply", we are likely to observe significant changes in the interbank repo rate and in microstructural characteristics of the repo market. So the alternative definition of supply surprise is appropriate in our view.

Description of OTC and Electronic Repo Markets and Construction of Liquidity Risk Indicators

The secondary repo market in Europe is surveyed on a semi-annual basis by the European Repo Council of the Securities Industry and Financial Markets Association (SIFMA). The survey provides a snapshot of the volume of repo trades outstanding on a single day in June and December each year and various other indicators of the market structure and growth. This survey reveals that repo volume reached a high point of 6,504 bln EUR in June 2007. It grew at a rate of roughly 20% each year between June 2001 and June 2007 and when the financial crisis hit it declined to 4,633 bln EUR in December 2008 before recovering to 4,868 bln EUR in June 2009. This implies that it was around the same size as the US inter-dealer repo market in US Treasuries in June 2007. Anonymous electronic trading represents about 25% of repo volume but this proportion has fluctuated recently with a surge in voice brokered business occurring at

the height of the crisis when a flight to liquidity required improved search mechanisms and an avoidance of counterparty risk. The most recent survey shows that more than 80% of collateral used in repos is made up of European government bonds and nearly 30% is represented by German government bonds alone. German government bonds held a steady share of around 25% in most of the previous surveys. Italian bonds are also well represented with a share of between 12 and 15% in recent surveys.

The segment of the secondary repo market that is studied here is the BrokerTec electronic, order-driven repo market provided by ICAP plc. The BrokerTec platform provides the leading venue for electronic inter-dealer trading in European repos mainly covering Euro zone government debt. There are more than 70 participating banks. Nearly half of these banks are also Primary Dealers in one or more of the underlying government bond markets[7]. All participants have equal access and rights on the trading platform. There are no designated or 'specialist' liquidity suppliers. To be able to trade most of the repo products available on the platform, participants are required to be members of the Central Counterparty clearing system or have access through a third party clearer. Since this is a collateralized lending market it has reduced counterparty risk relative to unsecured markets. Credit risk is further reduced because of the balance sheet netting, settlement netting and centralized margining for most repo contracts traded on the platform. There is substantial pre- and post-trade transparency in this market for all of the participants but there is no real-time provision of market data to non-participants. Participants can view available depth in the market. Limit orders are simply entered by participants and this provides opportunities for trading to occur. Trading is done only by accepting the specified quantities in the available limit orders. There is no negotiation over trade quantities or prices after trades are executed. The platform permits automatic replenishing of limit orders and pending orders are only visible to the firm entering the order. Pending orders do not have priority over 'shown' amounts at the same rate. Anonymity is preserved in most cases throughout trading and settlement (a Central Counterparty Clearer took both sides of all the trades considered in this study). The market automatically opens at

[7] There are 42 Primary Dealers listed as members of RepoClear and these are also members of the BrokerTec repo trading platform. RepoClear is part of the LCH Clearnet clearing house providing clearing, margin, netting and other facilities for trading on BrokerTec's repo platform; see, http://www.lchclearnet.com/membership/ltd/current_membership.asp.

06:45 London time and closes automatically at 17:15. Outside of these times the system will not allow an order to be entered. There is no special starting mechanism.

BTEC Data

The data from BrokerTec contains time-stamped records for all order events and trades conducted on the BrokerTec electronic platform for the period from March 2003 to March 2009 (our analysis concentrates on data from 2nd Jan 2006). This includes contracts for a wide range of repo collateral and terms to maturity. Secondary market repo volume was increasing in the pre-crisis period (see the Figure [10] below and also the reported increases in volumes on the secondary repo market according to SIFMA surveys). It is apparent that the crisis period characterized by generous funding by the ECB (through low, fixed-rate, full-allotment operations) is associated with reduced secondary repo market trading. Table [2] provides details about the incidence of trades and of "limit order" activity for General Collateral repo contracts. In total, there are almost 0.5 million order records and 130,000 trade records. It is clear from this table that most activity occurs for terms that are very short. Roughly 95% of GC activity is for contracts with start dates that are within a few days of the contract date and that last only a single overnight period.

The dataset contains records of transactions and limit order events associated with at least one general collateral contract for each country and a large number of specific collateral contracts. Table [3] shows the volume traded within different sub-samples for the GC contracts at 'overnight' (O-N), 'tomorrow-next' (T-N), settlement-next (S-N), one-week and one-month terms. Most activity is associated with general collateral repos at the "tomorrow-next" term and with specific collateral repos (usually about 6 bonds in each country) at the T-N and S-N terms. The GCs selected are mostly contracts that restrict the collateral to non-bills and bonds with maturity below 10 years (i.e., the most general contracts). Data for Belgium, Germany, Spain, France, Greece, Ireland, Netherlands and Portugal are included. Italy is not covered since most of the electronic trading activity in Italian GC repos is done on the MTS platform and only sparsely on BrokerTec. In the case of specific collateral contracts, we focus on repo data that pertains to the use of benchmark sovereign bonds at various maturities (the specific bonds chosen were benchmarks as defined by the MTS trading platform). Our selection is motivated by the availability of activity in the repo dataset. Our selection process gives a good representation of the entire dataset. It should be noted that there does exist a European wide

GC contract that is not traded on the BrokerTec platform. However, according to SIFMA surveys, German collateral represents the largest fraction of all collateral pledged against repo borrowing in Europe, so the German GC repo is probably more liquid than, and almost as general as, the European repo.

A reasonable reference point for our analysis is the German GC which is quite general in the type of collateral that can be delivered against it, is of high quality in terms of the credit worthiness of the issuer of the collateral and is a very liquid contract for most of the sample.[8] Most other contracts in Europe can be regarded as either more special or of lower quality (in terms of liquidity, credit quality and perhaps also in terms of the quality of counterparties involved).

4. Hypotheses and Econometric Approach to Testing

Our econometric methodology is designed to address two main propositions. These are;

Proposition 1:

1. Bidding aggressiveness and other indicators of 'funding liquidity risk aversion' in official ECB repo auctions is anticipated by similar variables in the secondary repo market.

Proposition 2:

2. Unanticipated auction outcomes affect quality of the secondary repo market (its microstructural characteristics and behavior).

We conduct our econometric analysis with data of daily frequency. Our daily data is based on averages of observations made at 15 minute intervals. This allows us to ignore many of the issues addressed by Brunetti *et al.*(2009) associated with intraday seasonality.

[8] It is not straightforward to compare different repo contracts across Europe on the basis of the repo rate alone. The effects of the maturity of the underlying bond and the term of the repo contract are complex enough but the degree of 'specialness' is another, potentially more important, confounding factor. This is because specialness drives repo rates down (perhaps to levels much lower than the German GC rate) while inferior quality (lack of liquidity or low credit quality of the underlying bond for example) will generally drive repo rates up. It is therefore possible that the rate pertaining to the use of a low quality bond of a periphery country could be special enough to drive repo rates into the same neighbourhood as the German GC rate.

As mentioned in the introduction, Drehmann and Nikolaou (2010) use bidding aggressiveness in ECB reverse repo auctions as a measure of '*funding liquidity* risk' (hereafter, for convenience, we will refer to this as 'liquidity risk'). It is therefore natural to consider whether there are analogous measures that can be compiled from microstructure variables in the secondary repo market. Brunetti et al. consider the effects of surprise outcomes ('news') from auctions as determinants of the changes in various measures of market quality post-auction. We consider similar effects but also examine whether secondary repo market conditions anticipate *liquidity* risk aversion in forthcoming auctions. A point of clarification is in order regarding our use of terms in the outline of our econometric approach. Contracts in the secondary market are traded as repos rather than *reverse* repos. In reverse repo auctions the cash funding is the object being bid for or offered while in repo markets the offers and bids are for the collateral. Thus, the aggressive bidding by participants in ECB *reverse* repo auctions is the analogue of aggressive offering (high offer yield) in the secondary repo market. Likewise, relatively high bid yields are equivalent to timid expressions of interest in acquiring collateral for funds provided. Aggressive ask yields in the repo market tend to be significantly above the expected official ECB target rate of interest (although this is not true for the period with fixed-rate, full-allotment auctions). When there is elevated *liquidity* risk aversion, bid-side yields will be significantly higher than the offer yields indicating that what is required to provide funding is a significantly higher yield (or spread) above what is being offered.

Let, 'A' denote the offer yield and 'B' denote the bid yield in the secondary market. If 'T' is the ECB official target rate then ln(1+A-T) is a measure of funding liquidity risk aversion which, if small enough, can be approximated by [A-T]. For convenience we make this obvious approximation elsewhere without alerts. We call [A-T] the '*ask target gap*'. Another indicator of liquidity risk aversion is how far bid yields exceed offer yields. We will call it the '*bid ask spread*'. Therefore [B-A] is an additional indicator of funding liquidity risk and it is possible that these two measures would interact multiplicatively to produce a more flexible indicator of such risk aversion. We leave the exploration of such non-linear effects for future research.

There are other microstructure variables that could provide additional information about *liquidity* risk aversion. We derive and use a variable to represent imbalance in liquidity on each side of the market. For example, a relatively small bid quantity could imply elevated *liquidity* risk aversion even if the bid yield is quite low. The imbalance in liquidity on the offer side relative to the quantity on the bid side of the market is likely to be indicative of heightened

liquidity risk aversion since it indicates excess latent demand for funding (we denote this as; LIQ = ask liquidity / bid liquidity). LIQ can also be included in the econometric specification on its own or as a multiplicative interactive term. We include such terms in our empirical analysis where they are significant. This regression is applied to data from the pre-full-allotment phase of the crisis (when auctions were still based on competitive bidding and discriminatory allocation).

Thus, to address *proposition 1*, we test whether indicators of repo market risk aversion can be used to explain the measured aggressiveness of bidding in forthcoming reverse repo auctions. Specifically, let $[Y-T]_t$ be denoted the '*target gap*', i.e., the difference between the weighted average rate and target rate occurring in the auction held on day t. In fact we can also consider other measures from auction results that could represent the same underlying risk aversion behavior such as the number of bidders or the amount bid in excess of what is normal or expected but we leave these alternatives for future work. Thus, taking the '*target gap'* as representative of *funding liquidity* risk aversion revealed by the behavior of participants in official auctions, we can test whether the following regression has explanatory power, and if so, conclude that such behavior is anticipated by pricing behavior and imbalance in order density in the secondary repo market in advance of auctions. The regression we employ in this case is as follows;

$$[Y-T]_t = a_0 + \sum_i b_i\,[A-T]_{t-i} + \sum_j c_j\,[B-A]_{t-j} + \sum_k d_k LIQ_{t-k} + a_1[Y-T]_{t-1} + \eta_t \quad (1)$$

Where the last term is a random error process and $i, j\ and\ k$ are positive integers generating a lag structure that is sufficient to incorporate potential statistical significance (we general allow for 4 lags in our empirical application). The lagged dependent variable is included as though it is a single period lag but this is misleading. The lag that is intended is an event period lag and this is generally more than a single period. In fact we include the previous outcome from all three of the main types of events examined in this study (namely, MROs, LTROs, LTROs and OTs).

The error in equation (1) can be considered the news (or unanticipated) part of the auction result. Since heterscedasticity is a feature of the dependent and explanatory variables we standardize all variables by use of an option implied variance from a major European stock market that is correlated with the underlying stresses in the repo market (namely, the VDAX). We simply divide all variables by the VDAX that was recorded four working days before the date of observing the dependent variable. The fourth lag was chosen because we use up to four lags

of the explanatory variables in the regression. We do not de-mean the variables before dividing by the lagged VDAX. It is more usual to use a fitted value for the variance when employing such a weighted least squares approach but we prefer to keep all our standardization consistent across all types of news variables and for the variables in the complementary regression that we outline below. The interpretation of the adjusted variables is simply as measures of *funding liquidity* risk relative to a more general risk indicator.

We note that equation (1) is different from the approach taken by Brunetti, Filippo and Harris (2009) in their study of the unsecured interbank market. They regard the news variable as directly observable. In the case of the repo rate itself, Brunetti et al. obtain predictions of the target rate and simply use the difference between this and the auction outcome as a news shock which they regard as potentially important in explaining the post-auction quality of the unsecured interbank market.[9] In the case of the repo market it is not clear that expectations about the target rate are a valid indicator of the true expectations of bidding aggressiveness in auctions. Our approach is also different in a less important way. This is regarding the frequency of our observations. We regard daily frequency as adequate in revealing the relation of interest.

Our second proposition is that the unexpected outcome of auctions adversely affects liquidity conditions in the secondary repo market in the post-auction period. This motivates a second regression which takes the error term from equation 1 and uses it as a surprise variable to explain liquidity conditions (or measures of liquidity risk aversion) in the secondary repo market in the days after the official operations. This part of our analysis follows quite closely the specification used by Brunetti et al. (2009) to study the effects of such operations on conditions in the unsecured interbank market.[10] The main difference is that we use the lagged value of the VDAX as a standardizing variable. Our model is as follows;

$$\begin{bmatrix} A-T \\ B-A \\ LIQ \end{bmatrix}_t = \begin{bmatrix} \alpha_0 \\ \beta_0 \\ \delta_0 \end{bmatrix} + \sum_{i=1}^{I} \begin{bmatrix} \alpha_i \\ \beta_i \\ \delta_i \end{bmatrix}' \begin{bmatrix} A-T \\ B-A \\ LIQ \end{bmatrix}_{t-i} + \sum_{k=l}^{K} \sum_{j=1}^{J} \begin{bmatrix} \alpha_{k,j} \\ \beta_{k,j} \\ \delta_{k,j} \end{bmatrix} \eta_{k,t-j} + \sum_{k=l}^{k} \varepsilon_{kt} \qquad (2)$$

[9] They compile rate expectations based on 27 separate *Reuters' Survey of Treasurers* involving 40 European commercial banks held during their sample period.

[10] They largely follow the approach taken by Andersen and Bollerslev (1998) and Andersen *et al.* (2002 and 2007).

Where the variables are the same as those described for equation 1. All variables (except η which is already adjusted) are standardized by using the four day lag of the VDAX. We examined the issue of causality between the VDAX and repo market uncertainty and this indicated that causality runs entirely from repo market uncertainty to the VDAX and not in the other direction.[11]

In the second phase of the crisis there is no indicator of bid aggressiveness in ECB auctions since all bids were satisfied at the policy rate. In fact, the surprise in the bids quantity rather than the rate itself may represent liquidity risk aversion in this phase. In this case the amount bid in excess of what might be considered normal (or above what is expected to be maturing) could be considered an indicator of *liquidity* risk aversion. If this is so, then we require only a replacement of the dependent variable in equation (1) to obtain evidence that the secondary repo market anticipates auction outcomes. We leave this for future work.

Our econometric specification involves a relatively large number of explanatory variables. Since there are a relatively small number of auction events (particularly SLTROs) in some of the sub-sample periods we easily run into difficulty with loss of degrees of freedom. We make some gains in estimation degrees of freedom in the case of regression (2) since we conduct the analysis jointly for different country-specific contracts. For some groupings it makes sense to apply parameter restrictions that improve estimation efficiency. This is only possible for the case of regression (2). The first regression is only conducted using independent variables based on the German GC-TN contract. The details regarding the specific restrictions we make and about the instruments we included are dealt with in the results section.

5. Results and Interpretation of Results

Description of variables

The secondary market indicators of 'funding liquidity risk aversion' were compiled by sampling the BrokerTec electronic orderbook. The orderbook was reconstructed using every limit order event and each trade event. This revealed the offer yield, bid-offer yield spread and the liquidity available at the three best bid and offer yields at each event. Our analysis is based on

[11] Results are available from the authors.

the daily average of observations made at 15 minute frequency. As described above, we examine the offered repo rates relative to the target rate set by the ECB.

To avoid a lot of repetition we give descriptions for the German General-Collateral Tomorrow-Next contract only. This is quite representative of the other contracts in our dataset. Thus, Table [4] contains the basic descriptive statistics relating to the explanatory variables used in regressions (1). Similar variables (based on country-specific contracts) are used in regression (2) and a SURE regression is employed so that parameter restrictions can be applied across some groups of countries or contract types. The news terms in regression (2) are always the same variables taken from the results of the first regression.

Note that, in the case of equation (1) the dependent variable is either the *marginal rate* or *weighted average rate* obtained in the ECB auction less the most recently announced target rate. We divide this by the VDAX(4^{th} lag). A similar variable is constructed from secondary market rates to act as one of the explanatory variables. In this case the target rate is subtracted from the average of the offer rate observed at 15 minute intervals for each date and this is divided by the VDAX(4^{th} lag). The bid-offer yield spread is treated in the same way (averaging over 15 minute observations and dividing by the VDAX). In the case of the relative liquidity variable (i.e., the ratio of offer quantity to bid quantity) we assume this can be set to 1 if there is no offer quantity or bid quantity and dropped where there is zero on the bid side. The descriptive statistics indicate that the basic explanatory variables do not have excessive outliers.

The descriptive statistics reflect the differences between the three periods studied. Even with division by the VDAX the basic statistics reveal the significant changes in conditions over the three main periods studied. Consider the Yield Spread relative to the policy rate. This has a mean of 3.572 bps in the pre-crisis period. It reduces in size in the first crisis phase to 1.761 bps and then becomes negative in the last period at -55.884 bps indicating that the interbank repo rate was at a large discount below the policy rate in the full-allotment regime. The same pattern applies for the standardized data despite the coincident rise in the VDAX. The bid-ask spread has a mean as low as 1.855 bps in the pre-crisis period. This rises to nearly 4.75 bps in the first crisis period and widens to 12.393 bps in the full-allotment regime.

Relative liquidity (ask quantity/bid quantity) is indicative of liquidity risk aversion in the sense that 'ask quantity' represents latent demand for liquidity while 'bid quantity' represents latent supply. Ask liquidity was generally much greater than bid quantity. Relative liquidity had a

mean of 1.745 in the pre-crisis period. This rose to 3.509 in the first crisis period and then dropped again to 1.831 in the full-allotment regime. It seems likely that the last period was associated with excess supply of liquidity and the reduced relative quantity reflects overall easing of conditions in the last phase.

The spread between the best offer and bid quotes (for TN GC contracts) averaged over core and periphery groups of countries, is shown in the Figure [11]. The VDAX index is also included to show the relation between general risk (and liquidity risk-aversion). The daily average volume at each of the first three levels of the orderbook (offer-side) for the GC Tomorrow-Next (TN) contract is shown in Figure [12]. There is progressively less liquidity deeper into the book. This also reveals that there was a slight growth in liquidity available at all levels through the crisis period. Figure [13] shows the liquidity on best three levels of the bid side of the market. It is important to note that there was generally more liquidity on the ask side of the book than on the bid side. This reflects an imbalance in latent demand for funds rather than for the collateral.

Discussion of results from Regression (1)

The results for the regression shown as equation (1) above are provided in Tables [5] and [6]. We show the case of the "away-rate" as dependent variable (this is the "weighted average bid rate" resulting in the auctions minus the policy rate). The regressions have explanatory variables (that predate the auction events) from the secondary market in German GC repo. We found the German GC contract to be quite representative of other countries that had liquid GC contracts. Table [5] contains the results for the MRO events while Table [6] contains results pertaining to all LTROs (standard or supplementary). In both sets of results the explanatory variables contain the lags of the dependent variable as well as lags of other similar variables from other types of events, (specifically, the "away-rate" and "target-gap" from the most recent previous auction of each type). These lagged variables act as controls for endogeneity of the other explanatory variables (i.e., the fact that they could be reflecting the effects of previous auction events rather than anticipating current ones. In both regressions three of the lagged auction result variables are highly statistically significant (not necessarily the same three).

The secondary repo market variables included in regression (1) are; (a) the ask rate in excess of the prevailing policy rate averaged over observations observed at 15 minute intervals denoted "AWAYGCDE", (b) the daily average bid-offer yield spread denoted "SYNGCDE", (c) the average

daily relative liquidity denote "LIQGCDE". The regressors and dependent variable are all standardized with respect to the VDAX and the explanatory variables from the secondary markets enter with 4 lags starting at lag 2 (pre-dating the announcements relating to the auctions).

In support of proposition 1 we would expect liquidity conditions to deteriorate in advance of auctions where more favorable conditions are expected (and in the market that follows). Thus predictably smaller excess weighted average rates in auctions should be associated with smaller excess yields in the secondary market in advance. The secondary market bid ask yield spread and the relative liquidity should also be positively related to the dependent variable which indicates generosity of supply at auctions. The results for the case of MRO events do not provide support for this proposition. All of the significant coefficients are in fact negative. The results for the LTRO events are mixed but more supportive of proposition (1) on balance. One of the significant coefficients on the lags of the "AWAY" variable is positive while two of the three significant coefficients on the lags of the bid-ask yield spread are positive. The only significant coefficient on the relative liquidity variables is positive.

Discussion of results from Regression (2)

The first 2 regressions provide us with residuals that form the basis of "news" variables relating to the outcome of the MRO and LTRO auction events respectively. These are explanatory variables in the regressions relating to Equation (2). This time the liquidity conditions in the secondary market are expressed as a function of recent surprise outcomes from the auctions. We allow 5 lags of the news variables enter in these regressions and also include 3 lags of the dependent variable from all three regressions in each of the three equations. Table [7] shows the results for the three regressions. This reveals a high degree of persistence in the microstructure conditions with the first lag of the dependent variables being very significant in their own regressions and often being quite significant in the other regressions. However, the main focus of our analysis is proposition (2) which requires that surprise outcomes from auctions (unexpectedly high settlement yields) would predict deterioration in liquidity conditions in the secondary repo market post-auction. This is consistent with positive impulse response coefficients with respect to the news variables in equation (2). We see from the significant estimated coefficients that the evidence is mixed for the case of MRO events. The

yield gap has a significantly negative response initially and then a mix of positive and negative coefficients on the lags. The initial response of the spread to MRO events is very significantly positive but there is no significant parameter beyond lag 1. Relative liquidity does not appear to have any significant parameters on the MRO shocks. The response to LTRO events appears to more consistently positive and in the case of the spread there are a number of significant lagged effects. The estimated impulse-response functions for the case of LTRO news is shown for the case of the three indicators of market liquidity in Figure [14] (yield minus policy-rate, bid-ask yield spread and relative liquidity respectively). These reveal that the reaction in the secondary market is for a temporary rise in stress indicators.

In the case of regression (2) we can extend the analysis to accommodate similar regressions for other countries. In particular, we jointly estimate the regressions for GC contracts in the case of Germany, Belgium and the Netherlands. The Seemingly Unrelated Regression (SURE) estimates of coefficients that are restricted to be equal across countries are given in table 8. Panel A contains the case where coefficients on the MRO news variable are restricted to be equal across the three equations. We see that the restriction is not rejected at the 5% significance level for the "awayrate" equation (almost acceptable at the 10% level). However, the coefficient estimates that are significantly different from zero are negative and this does not support the hypothesis that unexpected innovations to liquidity risk aversion in auctions causes deterioration in "awayrates" in the secondary market.

While the cross country equality restriction is not accepted for the case of the bid-offer yield spread as a function of the MRO news variables, we see that the first lag has a very significantly positive parameter. In fact, all of the other parameters estimates are positive although no significant. The "relative liquidity" variable also has a negative reaction to MRO news which does not support the hypothesis that deterioration in auction market conditions give risk to deterioration in the secondary market (although the cross equation restriction is comfortably satisfied).

Panel B contains the results for the case of cross country equality in coefficients on lagged news from LTRO auctions. In this case nearly all important parameters in all three equations are positive and many are significantly so. Also the cross country restriction is satisfied at the 10% level of significance or better in the case of the "awayrate" and "relative liquidity". There does not appear to be a declining response to news shocks for the case of the "awayrate" implying permanent effects. For the bid-offer yield spread the response coefficients begin positive,

becomes significantly positive at lag 2 and then becomes significantly negative at lags 4 and 5. In the case of the response coefficients for "relative liquidity" with respect to LTRO shocks, we note that all but the fifth lag are positive. The second lag is very significantly positive. In general, this set of results support the hypothesis that risk aversion displayed in auctions translates to similar situations in the secondary market. Panel C shows results for the case where response coefficients to both MRO and LTRO auction events are restricted to be equal across countries. This restriction is only accepted for the case of relative liquidity. In other respects the results do not change a lot from those of Panels A and B. The LTRO results seem most consistent with supporting the hypothesis being tested.

6. Conclusion

This paper initializes a line of enquiry aimed at understanding the effects of ECB auction events on secondary repo market microstructure particularly as a result of the financial crisis and the policy responses that it prompted. A detailed description of ECB monetary policy operations was provided and this revealed interesting information about the degree to which *funding liquidity risk* was relieved during two important periods of the recent crisis. The evidence obtained from this preliminary analysis suggests that the repo market conditions mirror the outcomes of official interventions. More favorable yields than expected at auction settlements give rise to more liquidity in the secondary repo market in the post-auction period. There is also some evidence that auction conditions are anticipated by the secondary market controlling for other causes. This was most striking for the case of longer term (including supplementary) operations.

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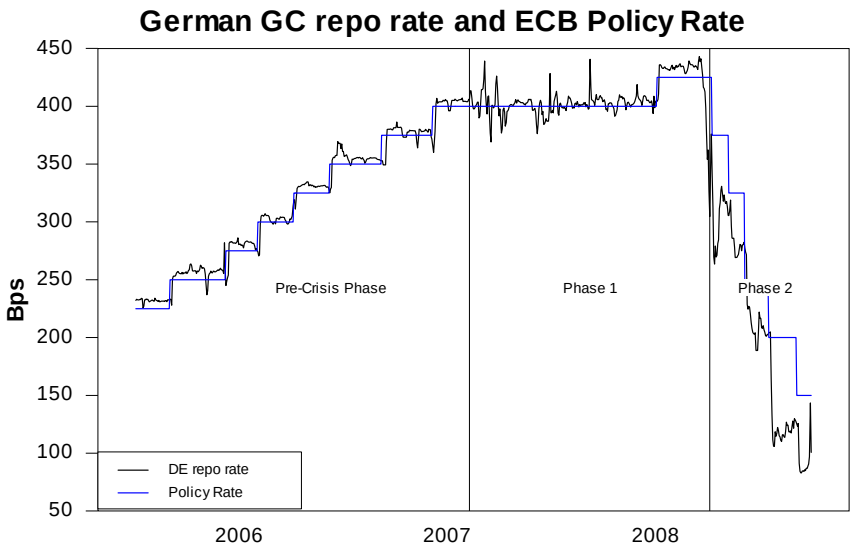

Figure 1: The yield for funding against Sovereign German General Collateral with term of 'Tomorrow-Next' is shown against the announced policy rate of the ECB. This shows that after the introduction of fixed-rate full-allotment auctions yields in the interbank repo market went below the target rate. The GC rate shown is a daily average based on mid yields observed at 15 minute frequency.

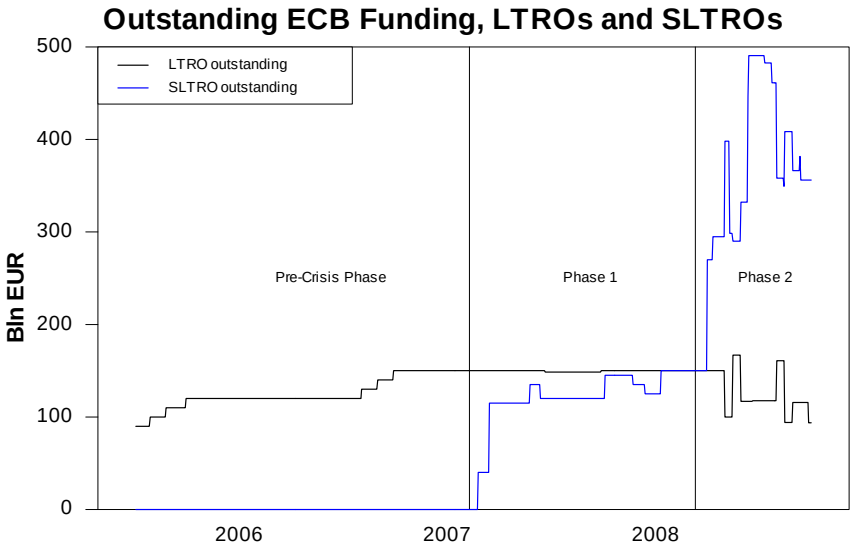

Figure 2: Outstanding funding related to ECB reverse repos from Long Term Operations and Supplementary Longer Term Operations.

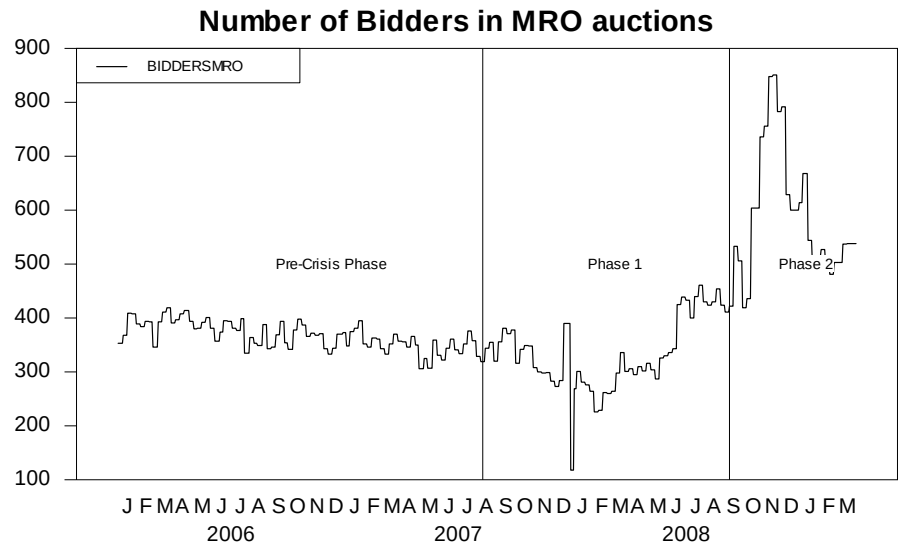

Figure 3: Number of bidders bidding for financing from the ECB as a time-series. MROs occur at weekly frequency.

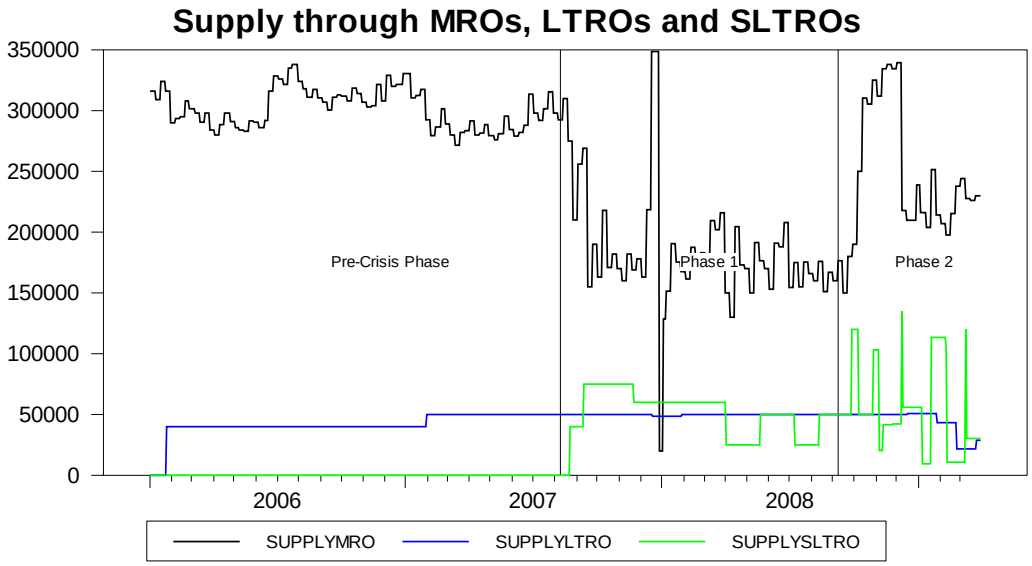

Figure 4: The Supply through different types of repo auction.

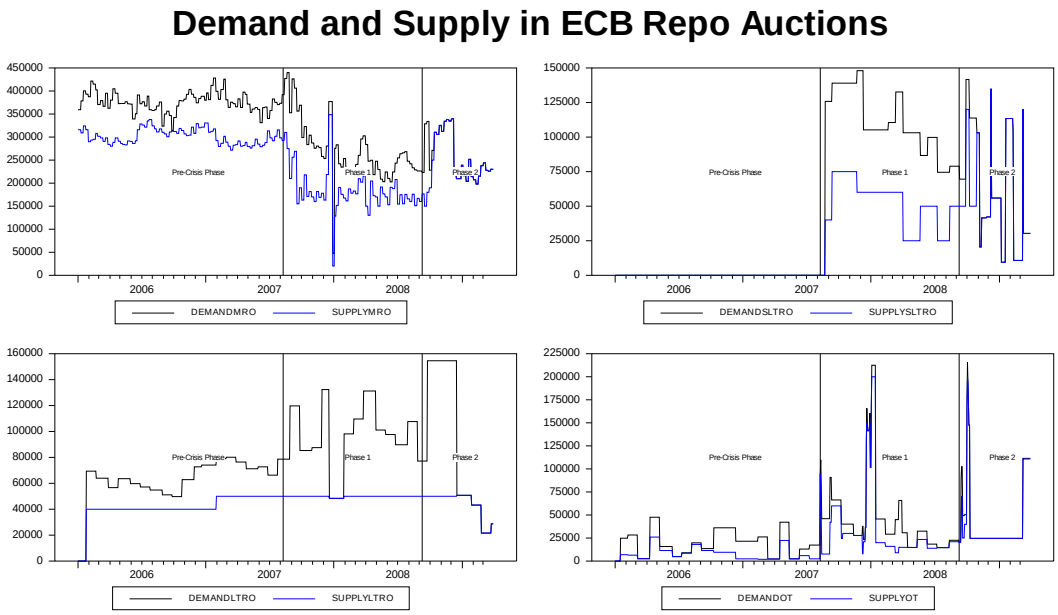

Figure 5: Supply and demand in repo auctions.

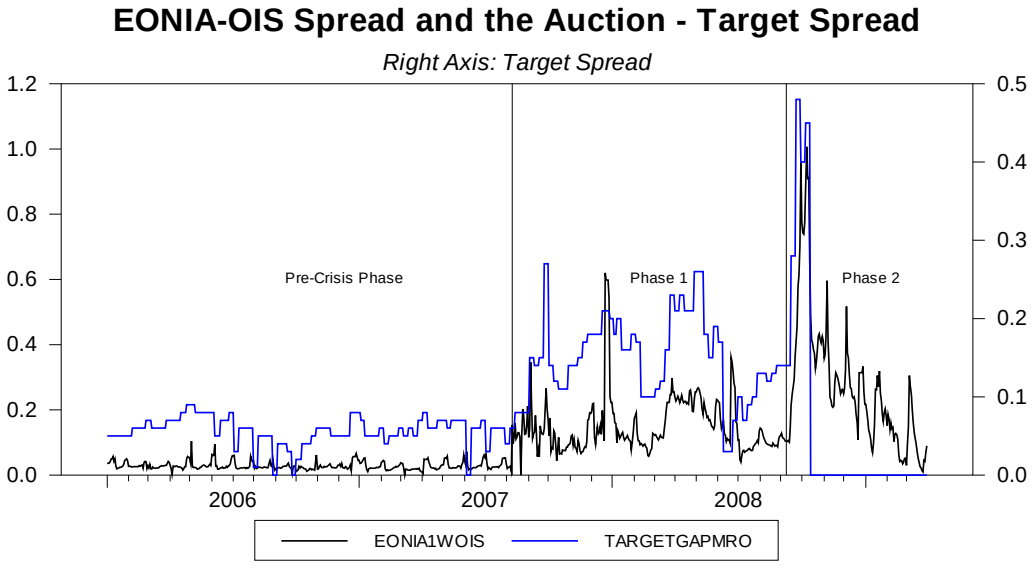

Figure 6: The deviation of the marginal rate obtained in ECB repo auctions from the rate intended. The EONIA-OIS spread is also shown and is suggestive of strong positive correlation. Note that in the last phase the allotment takes place at a fixed price so that there is no premium in auctions.

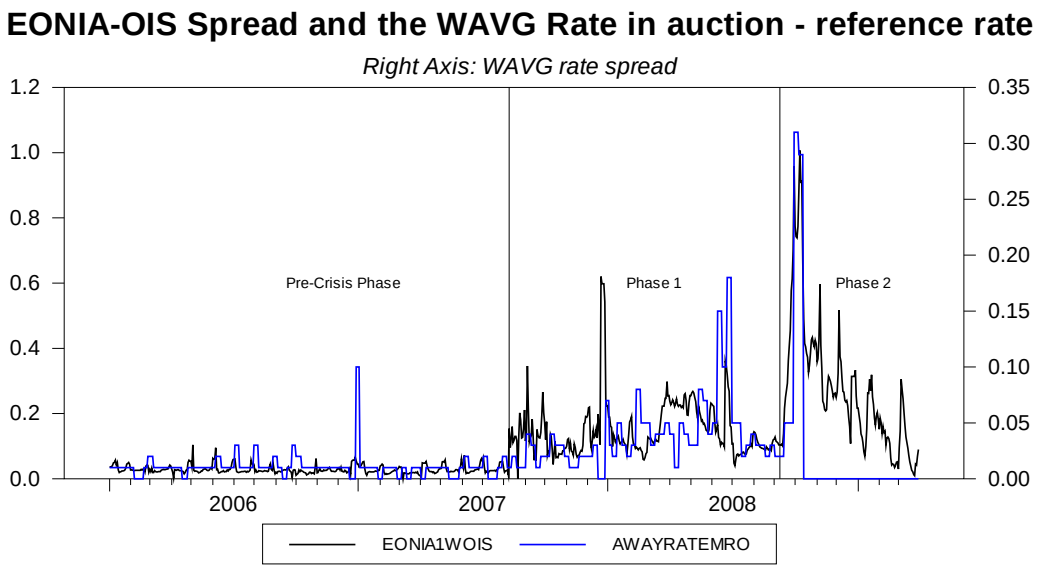

Figure 7. This figure shows the relation between the EONIA-OIS spread and the gap between the marginal rate and the weighted average rate obtained by participants in MROs.

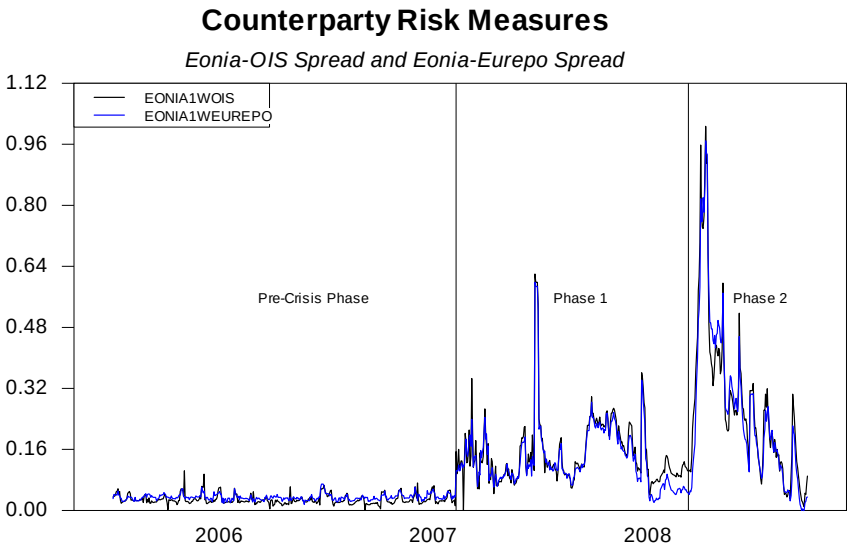

Figure 8 Counterparty Risk as measured by (i) the gap between EONIA 1-Week rate and the associated Over-Week Swap rate and (ii) the gap between EONIA 1-Week and associated 1-Week Eurepo rate.

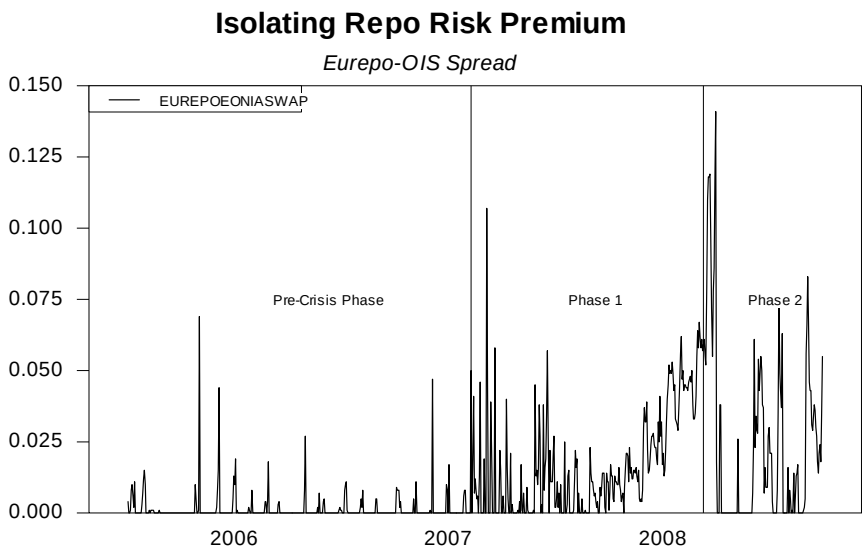

Figure 9: Repo risk premium as the difference between the 1-Week Eurepo rate and the 1-Week Swap rate.

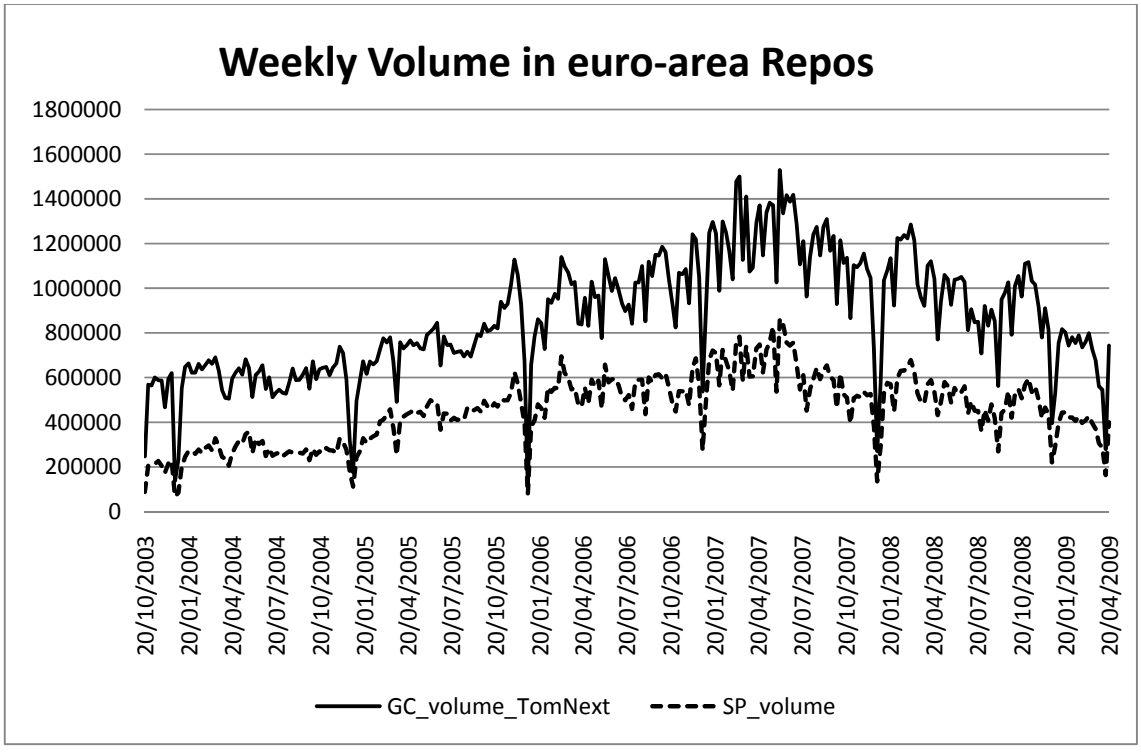

Figure 10: Volume of General Collateral Tomorrow-Next and Specials repo trading on the BrokerTec platform.

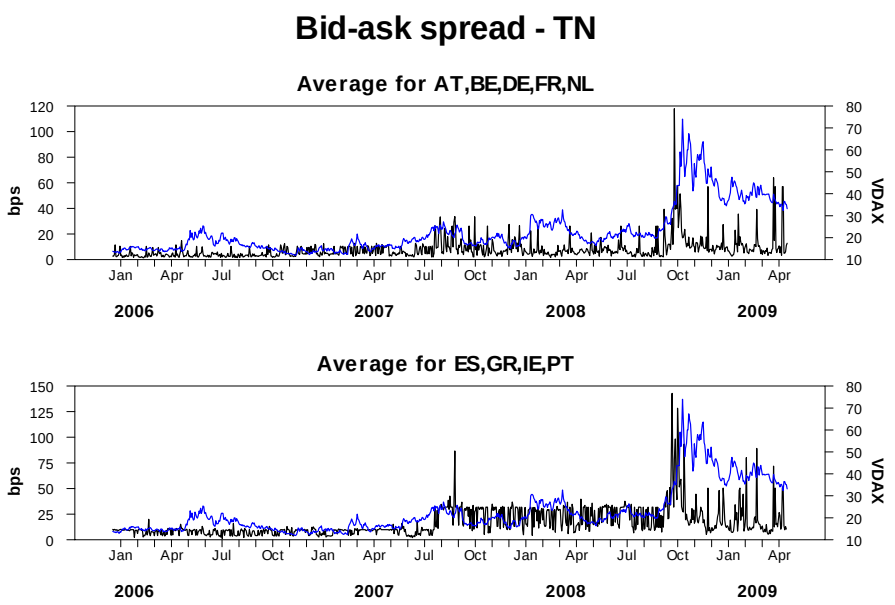

Figure 11: The Bid-Offer Spread is shown for various countries along with the VDAX index.

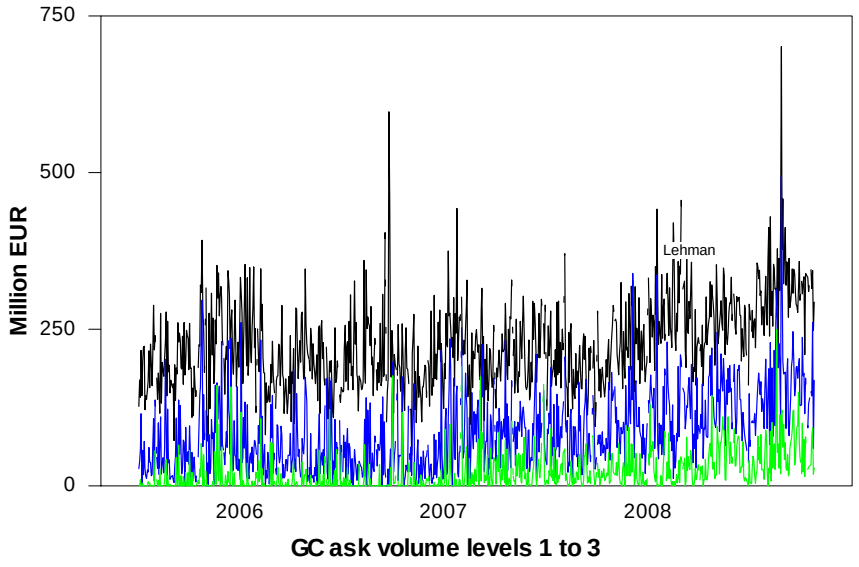

Figure 12: Volume at the first three levels of the offer side of the BrokerTec orderbook (daily average based on observations at 15 minute intervals).

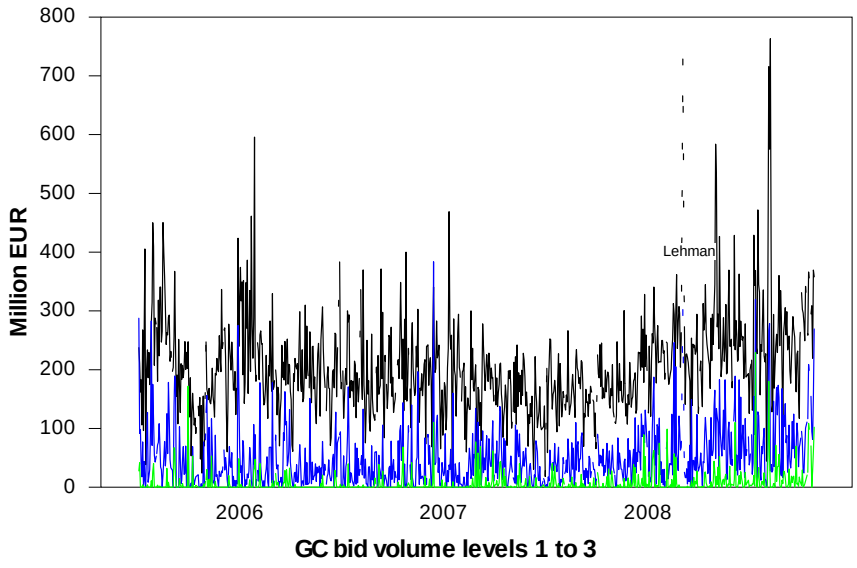

Figure 13: Volume at the first three levels of the bid side of the BrokerTec orderbook (daily average based on observations at 15 minute intervals).

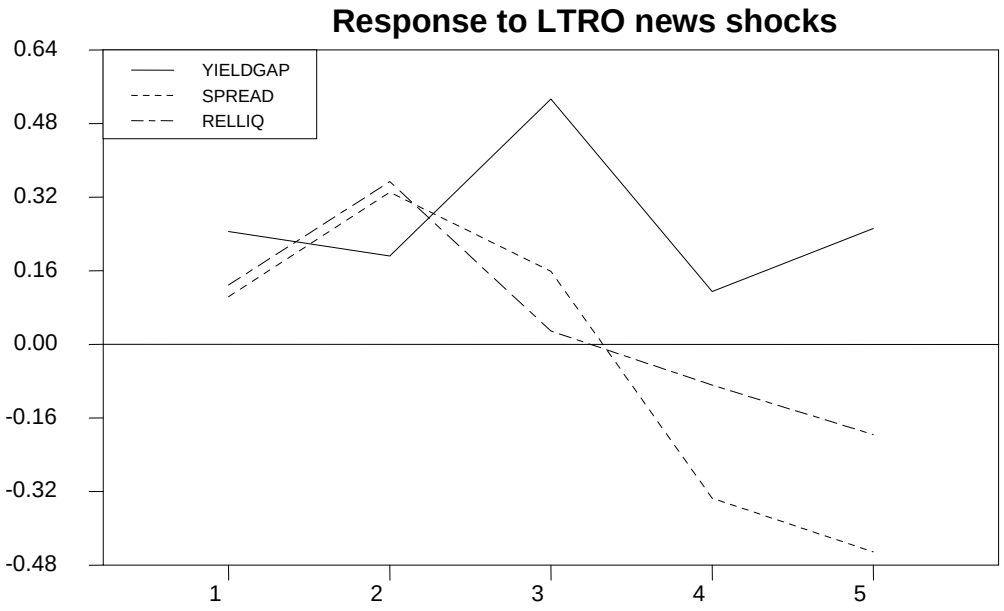

Figure 14: This displays the last 5 coefficient estimates in each of the three regressions shown in Table [7]. These can be regarded as impulse-response functions (the average response in each period following the auction surprise). The three response variables are the Yield Gap over the policy rate, the bid-ask spread and the relative liquidity (offer amount / bid amount). The raw variables were standardized using the VDAX index as explained in the text.

Type	Full Sample Jan 2006, Mar 2009	Pre-Crisis Jan 2006, Jul 2007	Pre-Full Allot Phase Aug 2007, Sep 2008	Full Allotment Phase Oct 2008, Mar 2009
MROs	166	83	60	23
LTROs	38	19	14	5
SLTROs	26	0	13	13
OTs	55	15	35	5
Total	285	117	122	46

Table 1: Number of official monetary policy operations by type and phase.

Term	Orderbook events	Trades
Overnights		
Overnight & O-Next	127,681	43,012
Tomorrow-Next	252,255	74,828
Spot-Next	33,910	4,926
Corporate-Next	557	68
Sub-total:	414,403	122,834
% of Total of Column	86.8	95.2
1 Week		
Overnight-Week	76	2
Tomorrow-Week	2,518	276
Spot-Week	21,514	2,870
Corporate-Week	7,394*	1,252
Sub-total:	31,501	4,400
% of Total of Column	6.6	3.4
2 & 3 Weeks		
O-2W,T-2W,S-2W or C-2W	5,345*	430
O-3W,T-3W,S-3W or C-3W	801*	84
Sub-total:	6,146	514
% of Total of Column	1.3	0.4
1 Month		
O-M,T-M,S-M or C-M	25,362*	1,298
% of Total of Column	5.3	1.0
Total	477,413	129,772

Table 2: Events on Orderbook and Trades, by Term and Type, May 05 – Apr 09. * Indicates that an adjustment was made to correct for a large number of orders in late 2006 that relate to a temporary testing of automated trading.

PANEL 1: Phase 1 the pre-crisis period										
Term	ON		TN		SN		Week		Month	
Country	Millions	Share	Millions	Share	Millions	Share	Millions	Share	Millions	Share
AT	3,600	0%	47,975	3%	1,475	2%	-	0%	200	1%
BE	21,375	2%	202,475	14%	6,725	9%	300	3%	2,125	14%
DE	109,250	12%	850,275	58%	52,875	72%	3,200	37%	3,300	22%
ES	100	0%	25,625	2%	3,400	5%	3,375	39%	2,575	17%
FR	750,450	84%	115,450	8%	50	0%	1,250	14%	6,600	44%
GR	-	0%	19,225	1%	175	0%	-	0%	-	0%
IE	-	0%	10,325	1%	6,750	9%	-	0%	-	0%
NL	8,225	1%	94,475	6%	1,175	2%	400	5%	-	0%
PT	-	0%	104,900	7%	500	1%	100	1%	250	2%
All	893,000		1,470,725		73,125		8,625		15,050	
PANEL 2: Phase 2 pre-Lehman crisis response										
AT	41,700	3%	52,100	3%	2,000	3%	2,175	1%	100	2%
BE	194,475	13%	222,900	15%	3,500	5%	4,500	2%	600	10%
DE	411,450	27%	751,575	49%	54,325	74%	234,725	93%	4,300	74%
ES	4,800	0%	3,725	0%	-	0%	200	0%	-	0%
FR	764,475	50%	197,300	13%	5,925	8%	6,700	3%	400	7%
GR	-	0%	173,875	11%	4,025	5%	2,575	1%	350	6%
IE	2,975	0%	6,775	0%	425	1%	375	0%	-	0%
NL	83,175	5%	78,775	5%	1,725	2%	1,775	1%	-	0%
PT	29,625	2%	42,450	3%	1,475	2%	450	0%	50	1%
All	1,532,675		1,529,475		73,400		253,475		5,800	
PANEL 3: Phase 3 post-Lehman crisis response										
AT	83,250	6%	36,625	1%	1,350	1%	9,200	4%	4,425	12%
BE	283,075	22%	296,750	12%	7,725	3%	12,975	6%	2,050	5%
DE	165,850	13%	1,601,375	65%	154,175	69%	169,925	72%	22,975	60%
ES	22,325	2%	14,175	1%	200	0%	825	0%	50	0%
FR	516,000	40%	181,650	7%	16,550	7%	14,725	6%	400	1%
GR	28,700	2%	147,275	6%	37,000	16%	1,825	1%	100	0%
IE	9,700	1%	18,275	1%	1,400	1%	950	0%	-	0%
NL	114,325	9%	111,900	5%	3,150	1%	19,100	8%	4,850	13%
PT	60,050	5%	63,100	3%	3,450	2%	5,075	2%	3,300	9%
All	1,283,275		2,471,125		225,000		234,600		38,150	

Table 3: Traded volume within phases by contract and by maturity terms. Max highlighted.

Panel A: Statistics for Raw Variables							
Full Sample(843 obs)	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-120.29	40.631	-6.053	4.023	640.853	-3.333	6.717
Bid-Ask Spread	0.500	75.285	4.463	2.464	40.367	1.392	5.000
Relative Liquidity	0.000	46.190	2.383	1.210	18.569	0.577	2.401
VDAX	11.91000	74.00000	22.55386	19.08000	113.79622	15.50500	24.07500
Pre-Crisis (415 obs)	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-39.85	31.952	3.572	5.392	64.968	3.708	6.943
Bid-Ask Spread	0.500	7.500	1.855	1.500	1.211	1.130	2.261
Relative Liquidity	0.000	30.000	1.745	0.954	8.198	0.392	1.974
VDAX	11.91000	25.42000	16.32728	15.47000	8.24410	14.23000	18.05000
Crisis Phase I (300 obs)	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-97.96	40.631	1.761	3.131	149.972	-1.267	7.561
Bid-Ask Spread	0.500	75.285	4.721	3.107	33.384	2.247	5.395
Relative Liquidity	0.000	46.190	3.509	1.658	37.635	0.821	3.269
VDAX	15.35000	36.59000	21.77547	21.28000	15.28580	18.84250	23.96500
Crisis Phase II (128 obs)	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-120.29	27.553	-55.884	-56.744	749.416	-76.223	-42.433
Bid-Ask Spread	2.571	57.583	12.393	9.380	100.337	7.247	12.663
Relative Liquidity	0.000	17.500	1.831	1.376	3.469	0.903	2.311
VDAX	34.45000	74.00000	44.76055	42.86500	68.55949	38.58250	48.11750
Panel B: Statistics for Standardized Variables (Division by VDAX)							
Full Sample	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-20.93795	8.41123	-0.71074	0.94977	18.04820	-0.77219	1.60957
Bid-Ask Spread	0.11114	13.67701	0.88020	0.56894	1.18078	0.33829	1.01507
Relative Liquidity	0.00000	11.46198	0.53985	0.26040	1.05087	0.12512	0.52017
Pre-Crisis (415 obs)	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-10.29449	6.88623	0.90432	1.34288	3.99925	0.85290	1.74352
Bid-Ask Spread	0.11114	1.99663	0.46660	0.36934	0.08581	0.28060	0.56996
Relative Liquidity	0.00000	7.75891	0.44142	0.23367	0.53291	0.09934	0.49140
Crisis Phase I (300 obs)	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-20.93795	8.41123	0.31386	0.68082	7.76396	-0.28242	1.59320
Bid-Ask Spread	0.11228	13.67701	1.04612	0.67401	1.51826	0.48009	1.21019
Relative Liquidity	0.00000	11.46198	0.78594	0.35341	2.07612	0.17415	0.69619
Crisis Phase II (128 obs)	minimum	maximum	mean	median	variance	fract25	fract75
Yield Spread	-20.93795	4.11799	-8.51450	-8.03475	19.11277	-12.11688	-6.14688
Bid-Ask Spread	0.42406	9.51953	1.88785	1.39846	2.73146	1.10007	1.83008
Relative Liquidity	0.00000	2.67215	0.27757	0.20259	0.08218	0.12975	0.33898

Table 4: Descriptive statistics for 843 daily observations of microstructure variables associated with the German Sovereign, General Collateral Repo contract for the 'Tomorrow-Next' term. The usual basic descriptive statistics are provided and in the last two columns we include the first and third quartiles denoted Fract25 and Fract75 respectively. Panel A contains statistics on the raw data. Panel B shows statistics for the variables actually used in the regressions, i.e., the raw variable after it is divided by the VDAX index observed 4 days in advance. The Yield spread is based on the mid-quoted yields observed at 15 minute intervals between the open and close of the BrokerTec electronic repo market. The calculation of the bid-offer spread is explained in section [**]. The liquidity variable (previous to division by the VDAX) is the average of the log ratio of offered quantity on the first three levels of the limit orderbook relative to the total bid amount on the first three levels of the orderbook (once again, the daily average is derived from observations taken from the reconstructed orderbook at 15 minute intervals).

Regression (1) - Dependent Variable: 'AWAYMRO' (The weighted average MRO rate less prevailing policy rate)
Robust Standard Error Calculations
Usable Observations 99 Degrees of Freedom 78 (Pre-Crisis and the Pre-Full Allotment Crisis Period)
Independent variables based on German GC-TN contract
Centered R Sq 0.62 R Bar Sq 0.522
Durbin-Watson Statistic 1.819

Variable	Coeff	Std Error	T-Stat
Constant	0.384	0.241	1.593
L2AWAYGCDE	-0.221	0.108	-2.046**
L3AWAYGCDE	0.020	0.068	0.299
L4AWAYGCDE	0.177	0.091	1.951*
L5AWAYGCDE	-0.122	0.056	-2.153**
L2SYNGCDE	-0.497	0.212	-2.343**
L3SYNGCDE	0.061	0.134	0.453
L4SYNGCDE	-0.183	0.162	-1.124
L5SYNGCDE	0.227	0.147	1.545
L2LIQGCDE	0.051	0.038	1.347
L3LIQGCDE	0.017	0.071	0.247
L4LIQGCDE	-0.116	0.043	-2.660***
L5LIQGCDE	-0.050	0.040	-1.246
LGAPMRO	0.093	0.119	0.780
LGAPLTRO	0.048	0.022	2.183**
LGAPSLTRO	-0.052	0.028	-1.797
LGAPOT	-0.383	0.139	-2.754**
LAWAYMRO	0.007	0.089	0.080
LAWAYLTRO	0.383	0.180	2.122**
LAWAYSLTRO	0.086	0.191	0.451
LAWAYOT	0.068	0.079	0.871

Null Hypothesis : The Following Coefficients Are Zero
Test 1: Zero Coeffs on... L0AWAYGCDE, L1AWAYGCDE, L2AWAYGCDE, L3AWAYGCDE
Test 2: Zero Coeffs on... L0SYNGCDE, L1SYNGCDE, L2SYNGCDE, L3SYNGCDE
Test 3: Zero Coeffs on... L0LIQGCDE, L1LIQGCDE, L2LIQGCDE, L3LIQGCDE
Test 4: Zero Coeffs on... LGAPMRO, LGAPLTRO, LGAPSLTRO, LGAPOT
Test 5: Zero Coeffs on... LAWAYMRO, LAWAYLTRO, LAWAYSLTRO, LAWAYOT
Result 1. F(4,*)= 1.449 with Significance Level 0.214
Result 2. F(4,*)= 2.302 with Significance Level 0.056
Result 3. F(4,*)= 2.457 with Significance Level 0.043
Result 4. F(4,*)= 2.237 with Significance Level 0.062
Result 5. F(4,*)= 3.164 with Significance Level 0.013

Table 5: Regression results for equation (1) applied in the case of the German GC contract. All variables are weighted by the fourth lag of the VDAX index. The dependent variable is the weighted average rate in MRO auctions expressed as a deviation from the prevailing policy rate. Lags of independent variables are generally indicated by the first 2 characters of the name, where L2, L3, L4 and L5 refer to lags of 2, 3, 4 and 5 days previous to the settlement date of the MRO auctions. In the case of lagged auction results the 'L' indicates that the result from the previous auction is included regardless of the number of days previous. The variables containing the last four characters GCDE are based on data from the secondary repo market in German General-Collateral Tomorrow-Next contract. Variables with MRO, LTRO, SLTRO and OT respectively as the final three characters refer to observations based on recent MRO, LTRO, SLTRO and Fine Tuning auctions results. The independent variables containing 'AWAY' in the name refer to the daily average of the offer yields on the German CG-TN contract observed at 15 minute intervals expressed as a deviation from the prevailing policy rate or, in the case of auction results, the weighted average yield reported for the auction as a deviation from the prevailing policy rate at that time. The independent variables containing 'SYN' in the name refer to the daily average of the bid-offer yield spread on the German CG-TN contract observed at 15 minute intervals. The independent variables containing 'LIQ' in the name refer to the daily average of the log of offer liquidity relative to bid liquidity on the first three levels of the orderbook for the German CG-TN contract observed at 15 minute intervals. Variables with 'GAP' in the name refer marginal rate less policy rate in past auctions.

Dependent Variable AWAY_SLTRO_LTRO (The weighted average SLTRO/LTRO rate less prevailing policy rate)
Usable Observations 38 Degrees of Freedom 17 (Pre-Crisis and Pre-Lehman Periods)
Independent variables based on German GC-TN contract
Centered R Sq 0.868 R Bar Sq 0.714
Durbin-Watson Statistic 2.83

Variable	Coeff	StdError	T-Stat
Constant	0.106	0.833	0.127
L2AWAYGCDE	-1.047	0.219	-4.781***
L3AWAYGCDE	1.657	0.688	2.408**
L4AWAYGCDE	-0.601	0.285	-2.105**
L5AWAYGCDE	-0.352	0.360	-0.977
L2SYNGCDE	1.293	0.487	2.653***
L3SYNGCDE	-0.156	0.307	-0.509
L4SYNGCDE	3.622	1.133	3.195***
L5SYNGCDE	-0.946	0.504	-1.876*
L2LIQGCDE	-0.249	0.170	-1.462
L3LIQGCDE	-0.194	0.332	-0.585
L4LIQGCDE	0.904	0.351	2.575***
L5LIQGCDE	0.187	0.226	0.830
LGAPMRO	-0.309	0.246	-1.255
LGAPLTRO	0.052	0.078	0.661
LGAPSLTRO	0.183	0.068	2.683***
LGAPOT	0.018	0.380	0.049
LAWAYMRO	-1.138	0.541	-2.101**
LAWAYLTRO	-0.406	0.250	-1.624
LAWAYSLTRO	0.152	0.711	0.213
LAWAYOT	1.192	0.556	2.143**

Null Hypothesis : The Following Coefficients Are Zero
Test 1: Zero Coeffs on... L0AWAYGCDE, L1AWAYGCDE, L2AWAYGCDE, L3AWAYGCDE
Test 2: Zero Coeffs on... L0SYNGCDE, L1SYNGCDE, L2SYNGCDE, L3SYNGCDE
Test 3: Zero Coeffs on... L0LIQGCDE, L1LIQGCDE, L2LIQGCDE, L3LIQGCDE
Test 4: Zero Coeffs on... LGAPMRO, LGAPLTRO, LGAPSLTRO, LGAPOT
Test 5: Zero Coeffs on... LAWAYMRO, LAWAYLTRO, LAWAYSLTRO, LAWAYOT
Result 1: F(4,*)= 6.199 with Significance Level 0.00005525
Result 2: F(4,*)= 8.418 with Significance Level 0.00000087
Result 3: F(4,*)= 2.349 with Significance Level 0.05189327
Result 4: F(4,*)= 3.383 with Significance Level 0.00894184
Result 5: F(4,*)= 2.435 with Significance Level 0.04504288

Table 6: The variables used in this regression are the same as those described in the caption for Table 3 except for the dependent variable which in this case refers to the weighted average rate obtained in SLTRO and LTRO auctions as a deviation from the prevailing policy rate. Once again all variables are standardized by dividing by the VDAX (lagged by 4 days).

Regression: Equations (2)
Dependent variables:

Average Yield in excess of Policy Rate
Bid-Offer Yield Spread
Relative Liquidity

Independent Variables:

Lags of Dependent Variables, i.e.,
Yield over Policy Rate,
Bid Offer Yield Spread
Offer Liquidity relative to Bid Liquidity.
Lags of News, i.e.,
Residual terms from equation (1) for MROs, SLTROs and LTROs.

	Dep: AVG_Yield_GCDE		Dep: Spread_GCDE		Dep:Rel Liquidity_GCDE	
Variable	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat
Constant	0.754	5.234	0.186	3.147	-0.716	-6.470
L1AWAYGCDE	0.910	21.639	-0.024	-1.442	-0.017	-0.516
L2AWAYGCDE	-0.162	-2.881	-0.035	-1.534	0.043	0.950
L3AWAYGCDE	-0.025	-0.568	0.001	0.082	-0.034	-0.978
L1SYNGCDE	-0.563	-4.715	0.914	18.668	0.114	1.250
L2SYNGCDE	0.134	0.878	-0.179	-2.858	0.233	1.998
L3SYNGCDE	-0.108	-0.849	0.072	1.384	-0.128	-1.321
L1LIQGCDE	0.101	1.717	-0.009	-0.371	0.243	5.336
L2LIQGCDE	0.015	0.254	0.008	0.338	0.112	2.396
L3LIQGCDE	0.087	1.464	-0.003	-0.150	0.107	2.316
L1NEWSMRO	-0.555	-1.968**	0.774	6.689***	-0.203	-0.899
L2NEWSMRO	0.673	2.025**	-0.112	-0.825	0.048	0.195
L3NEWSMRO	-0.465	-1.384	-0.073	-0.530	0.053	0.211
L4NEWSMRO	-0.116	-0.352	0.026	0.195	0.373	1.497
L5NEWSMRO	0.222	0.723	-0.025	-0.202	0.012	0.055
L1NEWSSL	0.245	1.046	0.103	1.077	0.129	0.740
L2NEWSSL	0.192	0.811	0.330	3.410***	0.353	2.011**
L3NEWSSL	0.533	2.235**	0.158	1.622	0.028	0.156
L4NEWSSL	0.114	0.458	-0.334	-3.259***	-0.088	-0.469
L5NEWSSL	0.251	0.994	-0.451	-4.345***	-0.196	-1.031
R_Bar_Sq	0.669		0.602		0.140	
DW	1.974		1.930		1.940	

Table 7: Results for regression associated with equation (2). Variables are as described in the caption to Tables [5 & 6].

Panel A: SUR with cross equation restriction…equality of **MRO** News coefficients						
	Dep: AVG_Yield_GCDE		Dep: Spread_GCDE		Dep:Rel Liquidity_GCDE	
Variable	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat
L1NEWSMRO	-0.432	-2.054**	0.375	4.881***	-0.002	-0.011
L2NEWSMRO	0.162	0.658	0.041	0.461	-0.444	-2.200**
L3NEWSMRO	-0.116	-0.459	0.017	0.188	0.236	1.091
L4NEWSMRO	-0.114	-0.437	-0.024	-0.252	0.302	1.387
L5NEWSMRO	0.006	0.027	-0.088	-1.051	0.184	0.935
Unrest Log-L	-733.304		-479.748		-937.785	
Restrict Log-L	-741.387		-503.391		-943.916	
Chi-Sq(10)	0.09498		0.0000		0.26803*	
Panel B: SUR with cross equation restriction…equality of **LTRO** News coefficients						
	Dep: AVG_Yield_GCDE		Dep: Spread_GCDE		Dep:Rel Liquidity_GCDE	
Variable	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat
L1NEWSSL	0.261	1.494	0.011	0.175	0.202	1.459
L2NEWSSL	0.266	1.506	0.151	2.342**	0.366	2.472**
L3NEWSSL	0.512	2.793***	0.051	0.766	0.141	0.959
L4NEWSSL	0.188	1.039	-0.129	-1.959*	0.098	0.646
L5NEWSSL	0.374	2.016**	-0.184	-2.734***	-0.141	-0.889
Unrest Log-L	-733.304		-479.748		-937.785	
Restrict Log-L	-740.977		-502.352		-942.766	
Chi-Sq(10)	0.1199		0.0000019		0.44406*	
Panel C: SUR with cross equation restriction…equality of **MRO & LTRO** News coefficients						
	Dep: AVG_Yield_GCDE		Dep: Spread_GCDE		Dep:Rel Liquidity_GCDE	
Variable	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat
L1NEWSMRO	-0.436	-2.071**	0.388	4.991***	-0.001	-0.007
L2NEWSMRO	0.165	0.667	0.032	0.360	-0.451	-2.233**
L3NEWSMRO	-0.116	-0.460	0.020	0.216	0.238	1.099
L4NEWSMRO	-0.116	-0.445	-0.011	-0.118	0.299	1.378
L5NEWSMRO	0.008	0.037	-0.093	-1.099	0.194	0.987
L1NEWSSL	0.265	1.515	0.014	0.218	0.202	1.461
L2NEWSSL	0.263	1.486	0.163	2.502**	0.362	2.441**
L3NEWSSL	0.518	2.816***	0.053	0.793	0.139	0.940
L4NEWSSL	0.184	1.014	-0.132	-1.976**	0.094	0.617
L5NEWSSL	0.379	2.035**	-0.193	-2.833**	-0.139	-0.877
Unrest Log-L	-733.304		-479.748		-937.785	
Restrict Log-L	-749.586		-526.275		-948.386	
Chi-Sq(35)	0.03765		0.0000.		0.38545*	

Table 8: SURE regression results associated with equation (2) estimated for countries Germany , Netherlands and Belgium (DE, NL & BE). Equality restrictions are imposed on parameters for news variables across countries. Panel A contains the results for SUR regression with equality restrictions on MRO news parameters. Panel B involves the results for the case of restrictions on the LTRO news variable. Panel C involves results for restriction on both news variables. Variables are as described in the caption to Tables [5 & 6].