ECB Monetary Policy and the Interbank Repo Market

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Abstract

We examine the relationship between ECB monetary policy actions and microstructural developments in the euro interbank repo market where funds for reserve management are borrowed and lent against sovereign collateral. Prior to the sub-prime crisis of mid-2007, we find that ECB liquidity-providing operations had very little influence on interbank trading of reserve funding. Conversely, there is a high degree of sensitivity of repo market conditions to eight policy rate changes that preceded the crisis. This reaction is strong and quick relative to usual monetary policy effects. The analysis is then extended to the first stage of the financial crisis - before the Lehman Brothers collapse. We find that there was insufficient flexibility in allotment at auctions and this led to aggressive bidding and price effects that encouraged more reliance on an already stressed interbank market. We highlight the potential advantages of using variable-rate flexible-allotment as part of a future tapering of non-standard operations.

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1 Introduction

Notwithstanding the high-frequency evidence provided by Brunetti, Filipo and Harris (2009) for a small segment of the unsecured interbank market, there is a shortage of conclusive evidence (for the case of ECB operations) of a well-established relation between the behaviour of banks in monetary operations and their interbank market activities.[1] Demiralp and Carpenter (2006a, 2006b) investigate, and find evidence of, an anticipation effect in the federal funds market in the US around target rate announcements and interventions, as well as liquidity effects on the last days of maintenance periods, but this is quite a different institutional setting to that of the euro area. Beaupain and Durré (2012, 2013) consider how bid-ask spreads, depth and resilience behave in a segment of the unsecured interbank market over different operational regimes. This has some similarities with our analysis but repo markets have not been studied in this way.

Limited information about this relation casts doubt on our current understanding of the reliability of the mechanism through which monetary policy is supposed to operate. We also know too little about how this mechanism was affected by the financial and sovereign debt crises of recent years and the policy responses to them. A better understanding of this relation and how it has changed throughout the crisis is crucial to inform the debates about how best to return to normal operations and about whether changes are needed in the operational framework.

For the case of the euro area we examine the relationship between microstructure characteristics of the interbank market (where funding for liquidity is traded using sovereign bonds as collateral) and the outcomes of monetary policy reserve operations. Firstly, for the non-crisis regime, we test for causal links between bidding aggressiveness in monetary operations and interbank trading activity subject to maintenance period seasonality. Our

[1] In the case of Brunetti et al (2009) the evidence presented is only relevant to a very high frequency interaction between unsecured interbank activity and auction outcomes/behaviour during the early stages of the financial crisis (evidence shown in Mancini, Ranaldo and Wrampelmeyer 2013, suggests that the unsecured market is a relatively small proportion of all interbank trading of funding for liquidity and the segment studied by Brunetti et al. is itself only a small proportion of unsecured trading). Some evidence of the effects of the non-standard very long-term liquidity providing operations (VLTROs) conducted by the ECB during the sovereign debt crisis in the euro area periphery is discussed by Mancini et al. (2013). They argue that official liquidity provided through VLTROs had no significant effect on interbank activity or rates. They interpret this as a type of *liquidity trap*.

empirical model follows the structure proposed in Mancini et al. (2013) and contains terms to control for anticipation of interest rate changes (as in Demiralp and Carpenter, 2006a, 2006b). This reveals price and quantity effects consistent with the substitutability of these two sources of liquidity but our results portray a very weak degree of substitution.

Secondly, we use the pre-crisis empirical model as a basis to examine the effects of eight interest rate changes that preceded the market turmoil of mid-2007. This reveals statistically significant and surprisingly strong contractionary effects arising from these rate changes and we consider whether this was more a sign of stresses in the functioning of the interbank market rather than due to the actual or anticipated macroeconomic effects of the rate increases. It is plausible that monetary policy affects interbank market behaviour through the anticipation of the eventual effects of rate changes - as a result of interest rate rises eventually feeding back to reduced economic activity and an eventual shrinkage in transactions/reserve needs. But such changes would be expected to be small and to arrive with significant lags due to the time it takes interest rates to affect real economic activity. We consider whether an alternative causal effect can be implicated - i.e., whether a change in risk appetite and a contagion arising from the deterioration in the credit quality of banks' assets could be responsible.

Thirdly, we extend the focus of our analysis into the pre-Lehman crisis period - when the policy response, together with risk appetite, collateral quality and counterparty risk developments, become the main influences on interbank market activity. A structural specification for the relationship is proposed to cater for the crisis circumstances. This is used to isolate the changes in repo markets that can be traced to auction supply and demand innovations (i.e., mainly policy-related responses to the crisis). We also include a partial analysis of the post-Lehman crisis period when fixed-rate full-allotment auctions were introduced.

As in Mancini et al., 2013, we combine data from three main sources namely, (i) EUREX GC Pooling repo trading data, (ii) high frequency intraday microstructure data obtained from the BrokerTec Repo trading platform run by ICAP plc and (iii) MTS repo trading information obtained from the Repo Funds Rate web service.[2] We also make use of the

[2]The MTS market is where predominantly Italian bonds are used as collateral in repo trading. The Italian repo market is a relatively large market and we acknowledge that our results may not be representative of this segment.

daily survey of trading in the EONIA market to control for substitution effects from this source. Mancini et al. focus their analysis on activity in the Eurex GC-Pooling Basket and they do not examine the nature of the interaction between interbank activity and official operations (or interest rate changes). In contrast, these issues are our primary focus. We rely heavily on BrokerTec data to represent activity in the wider repo market.[3]

The BrokerTec repo trading platform represents by far the majority of automated interbank trading in short term funding. According to ICMA surveys, BrokerTec repo trading activity represents about half of all automated trading activity in repos that use euro area sovereign bonds as collateral and about 15% of all repo trading by main euro area banks. While price discovery in the BrokerTec market may reflect collateral shortages and repo *specialness* this does not mean that the funding side of the market is irrelevant for banks' liquidity management. In contrast to Mancini et al., we take the view that specialness, if anything, augments the attractiveness of this market as a source of funding for liquidity, since even small degrees of specialness represent economically large benefits for the large number of banks that already participate on this trading platform. To conduct the microstructural part of our analysis we reconstruct the order books of individual repo markets on this trading platform over a nine year period (2,381 trading days). This involved processing almost 104 million order book records.

This paper contributes to a more general literature concerned with repo markets and monetary policy.[4] It broadens the recent analysis of the euro area repo market by Mancini, Ranaldo and Wramplemeyer (2013, 2015) by introducing the relationship between this market and monetary policy actions. It also contributes to work on monetary policy operations of central banks and, in particular, of the ECB. Borio and Nelson (2008) provide a general background to the operational effects of the financial turmoil of 2007 and, Cour-Thimann and Winkler (2013) provide a description and assessment of the ECB's non-standard monetary policy measures during the early phases of the crisis. In Bindseil, Nyborg and Strebulaev (2009), weekly repo auctions of the ECB are examined to gain an understanding

[3]Our reliance on the BrockerTec data is appropriate - particularly for the pre-crisis analysis - since the EUREX platform only came into existence in March 2005 and its market share grew quite slowly initially. While Mancini et al find evidence to suggest that the EUREX segment of the repo market was robust during the financial crisis, it remained overall a relatively small proportion of total interbank repo activity.

[4]A related literature concerns the contribution of interbank payment systems to systemic risks but not in relation to monetary policy operations, see Rochet & Tirole 1996a and 1996b.

of how bidding strategies affect auction outcomes. Their analysis includes an indirect assessment of how interbank markets (specifically, interest rates in the unsecured interbank market) affect auction behaviour. Drehmann and Nikolaou (2009, 2013) examine bidding behavior in ECB funding operations during the crisis and find that it is 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 to avoid being rationed at the marginal rate - or completely excluded from supply if the marginal rate turns out to be very high relative to expectations. We show that this behavior reflects deteriorating conditions within the interbank repo market (where banks were previously able to plan their liquidity provision) and it produced a protracted policy response that had feedback effects within the post-auction interbank repo market.

Section 2 describes how liquidity provision by the ECB operates and explores the likely substitutability of official and interbank funding for liquidity management. Section 3 concerns the modelling strategy and methodologies adopted for the pre- and post-crisis regimes. In section 4 we discuss the data used in the analysis including variables used to explain structural change in the relationship during the crisis period such as; an index of country-specific changes in bank CDS spreads, the EURIBOR-OIS spread, sovereign bond CDS spreads and microstructure variables from the interbank market. Results are discussed in section 5 and this is followed by a concluding section where policy implications and proposals for further work are outlined.

2 ECB Auctions & Repo-Markets in Normal Times & Crisis

In normal circumstances the ECB conducts monetary policy by imposing reserve requirements on banks while simultaneously supplying liquidity through refinancing operations (i.e., by auctioning funding - for liquidity management purposes - in return for collateral in weekly (one-week term) *main refinancing operations* (MROs) and mid-maintenance-period (3 month term) *longer-term refinancing operations* (LTROs)). In essence, transfers of funds among banks enable payments of bank customers to be made more efficiently. The rate of return on reserves is determined by the weighted average rate at which refinancing operations were settled in a previous maintenance period and this normally tracks the ECB's target interest rate very closely. Banks can use interbank transactions to top-up (or share) their reserves and they can also manage their reserves by accessing liquidity made available through the ECB's refinancing operations.

Since reserve requirements must only be met on average (over approximately monthly reserve maintenance periods), banks have a significant degree of flexibility in allowing reserves to temporarily deviate from required levels.[5] This facilitates substitution of the sourcing of liquidity across time as well as across alternative sources. This flexibility, of course, diminishes as the end of each maintenance period approaches and banks usually prefer to front-load their reserve management to guard against breaching their requirements when it is expected to be most expensive at the end of the maintenance period. Our empirical modelling is conducted at the frequency of the Main-Refinancing Operations (weekly) and all interbank variables are average daily amounts across days between the auctions. We address the maintenance period timing effect by including a one-period and fifth-period lag in our empirical model since most maintenance periods are of 4 to 5weeks in length. We also control for much more pronounced seasonal effects around the end of the year.

Even with adequate controls for maintenance period effects there are substantial challenges involved in assessing how interbank and official funding sources relate to each other. For example, in the pre-crisis period there was a non-stationary pattern to trading activity in the interbank market while at the same time nearly all aspects of auction outcomes were stationary (Mancini et al. 2013 simply use a linear time trend in their specification to account for the non-stationarity of interbank market activity). We model the implicitly relationship between 'repo roll-over' and auction outcomes for the pre-crisis period (i.e., the excess or shortfall in new repo transaction value relative to what would usually be expected given the volume of maturing repos is modelled as an error correction relation, ECM). Repo roll-over innovations are shown to affect outcomes of auctions and to be related to previous auction outcomes. An event analysis is applied to show that cumulative abnormal innovations in repo-activity is related to ECB interest rate setting from late 2005 to June 2007 with roll-over excesses increasing before interest rate increases and then declining sharply afterwards.

[5] In the recent past, reserves were required to be 2% of short term liabilities reported two months prior to the beginning of a given reserve maintenance period. In December 2011 this requirement was halved to 1%.

The crisis introduced a number of complications to assessing the relationship between interbank and official funding sources due to the frequency and size of structural shocks that occurred. The structural changes are eventually shared by the two funding venues but it is plausible (or very probable) that they originate in the interbank market as idiosyncratic effects. The contrasting time series properties of the two principal endogenous variables does not rule out meaningful interactions but it limits the nature of the causal relation we can uncover empirically. Therefore, for the crisis period we propose a semi-structural model that identifies cross-venue effects that can be identified as primarily due to auction policy.

The first important crisis regime is the period from mid-2007 to immediately before the Lehman Brothers collapse in September 2008. This period was characterised by frequent liquidity contractions within the interbank market, and this (i), changed how banks behaved in monetary policy operations and (ii), prompted some flexibility in how monetary policy operations were conducted. Some banks were prepared to bid very aggressively in reserve auctions while the amount of reserves that was allotted in auctions was permitted to rise above what would normally have been regarded as sufficient to satisfy average reserve requirements.

Absent the effects of the actual increase in allotment quantity at auctions in this period, the more aggressive bidding behaviour (as described by Drehmann and Nikolaou 2013) can be regarded as having two competing effects. Firstly, it distributed relatively more reserves to weaker banks and eased localised liquidity difficulties. This would have reduced the need for interbank trading by banks that received such allocations. Secondly, it raised the average cost of official funding for other banks (and it increased the risks that these banks would be outbid and therefore not allocated any of the reserves supplied at auctions). Anecdotal evidence also points to the emergence of a stigma attached to obtaining funding through these more flexible and more expensive operations.

Banks with sufficient access to good collateral were therefore incentivised (through the price effect and their avoidance of a stigma effect) to resort more heavily to the interbank repo market. Whether the more targeted allocation of reserves to the most-needy banks or the relative price effect was more important in explaining the changes in interbank trading is a matter for empirical investigation. This provides us with an exceptional opportunity to measure the effects of flexible allocation of reserves in official operations (conducted as variable rate auctions) and it motivates the case for such operations during the re-normalisation process so as to maintain sufficient liquidity while incentivising structural reform in banks' asset and liability management exercises.

3 Model and Econometric Approach

Our empirical analysis of the pre-crisis period aims to identify the nature of the relationship between monetary policy operations and the interbank market which are normally regarded as substitutes. There are some obvious signs that these venues for funding are disconnected and this influences our model specification. The disconnect is apparent in the relationship between liquidity provided by the ECB and the volume of activity in the interbank market (the growth in combined MRO and LTRO allotment appears substantial but this mainly reflects the growth in the size of the euro area). Interbank market activity, Q^{repo}, was on a very different path from the relatively stable provision of liquidity by the ECB. We discuss below some structural developments that may explain this disconnect. On the other hand, the price outcomes from auctions (weighted average settlement rate relative to the policy target rate), P^{auc}, is a *stationary* series.[6] Auctions during this period involved a planned allotment based largely on maturing amounts from previous auctions and the planned allotment was announced in advance. Auction bids appear to have been influenced by a belief that the intended policy rate would be achieved and be the driver of short term rates more generally (banks were tacit price-takers and followed the announced/credible policy target).

In contrast to the pre-crisis stationarity of P^{auc}, this becomes disconnected from the target rate - and non-stationary - during the first part of the crisis (specifically in the period from mid-2007 to the Lehman collapse). This reflects an increasing willingness of the ECB to adjust the settlement rate as well as the allotment quantity in auctions as a response to the persistent aggressive bidding behaviour by banks - and these actions may

[6]The weighted average settlement rate is provided by the ECB after auctions. This is based on the rates that were bid by banks that were allocated funds. The weights are the proportions that each bank's allocation represents of the total amount allotted (the auctioneer apportions the planned allotment to banks starting with those that bid the highest rates and stops when the planned allotment is spent). According to Drehmann and Nikolaou (2013) this is a good proxy for the intensity of auction bidding and we use this in excess of the ECB deposit rate in the empirical analysis as the price outcome from auctions.

even have undermined the credibility of the target rate. In this regime there are potentially multiple stochastic trends in the P^{auc} series (i.e., the accumulated effects of shocks to the liquidity needs of banks, changes in bidding behaviour as a reaction to being out-bid in previous operations and innovations in the ECB's auction policy stance). The ECB put a stop to the dis-anchoring of the auction settlement rate and the intended rate soon after the Lehman collapse by the introduction of fixed-rate full-allotment auctions. Trivially, in the post-Lehman period P^{auc} is fixed and quantity allotted in auctions becomes interesting. In this period we model quantity demanded/allotted as a cause of (and function of) interbank activity.

As mentioned, Q^{repo} is non-stationary - and disconnected from ECB operations - across the entire sample we study, but this is probably for different reasons depending on the regime. There are two competing stories for this in the pre-crisis period. One concerns developments in the repo market and a change in the funding models of banks while the other involves loose monetary policy. Innovations in the network efficiencies of the market as well as innovations in drivers of repo activity related to macroeconomic and financial developments could certainly matter for the efficiency with which any stock of reserves can be leveraged. There is ample anecdotal evidence that securities lending became easier and less costly and this facilitated permanent changes in repo-related leveraged speculation and shorting. Efficiency gains in the trading of repos and in the underlying collateral used in repos can also be attributed to the introduction of electronic trading platforms and better settlement mechanisms. Occasionally there were also innovations in how counterparty risk was managed through margin mechanisms.[7] Many banks were also relying less heavily on deposits as a source of funding for their lending activities and since reserve requirements are based on such liabilities the required reserves were not growing in line with underlying transactions demand. These structural developments are plausible explanations for the disconnect between interbank activity and liquidity management by the ECB, but there was also a persistently low policy rate for most of the post-Dot-Com/pre-crisis period, and this loose policy stance likely contributed to the relaxation of constraints on interbank activity (simply a widespread willingness to lend and borrow based on what seemed to be

[7] In addition to these structural changes, other potential sources of non-stationarity arise from using the trading activity from a single trading platform because of movements of activity across venues and between unsecured and secured activity. This adds to the need for a joint analysis of repo activity and price across the main competing venues.

a reliable source of short-term funding).[8]

While liquidity operations do not seem influential in advance of the crisis, in contrast, the contraction of interbank market activity during the period of monetary tightening (previous to the crisis) reveals strong effects. But what explains these effects? To support the assertion that interest rates transmitted to real effects through a risk channel it is important to control for the normal relations that would have applied when transactions requirements were adjusting to normal economic fluctuations. Using the pre-crisis econometric specification as a baseline for the expected relation between the interbank sharing of liquidity and banks' behaviour in ECB auctions, provides us an opportunity to conduct an event analysis to assess how interest rate changes, in non-crisis circumstances, affects the workings of the interbank market.

Interbank repo volume during the crisis period becomes disconnected for more obvious reasons (being constantly affected by crisis events and the policy responses). These effects include shocks to collateral quality, collateral and liquidity hoarding, shocks to counterparty risk and to uncertainty about where such risks were located. In addition, it is plausible that ECB auction policy (including innovations in the repo rate, auction term and allotment amounts) and changes in the aggressiveness of bidding in auctions, affected the amount of interbank trading that was required to achieve reserve requirements. And since banks were restructuring their balance sheets, there were continual structural changes in the required level of reserves. Clearly, some aspects of the crisis-related stochastic trends become common to auction outcomes and interbank market activity, but some remain idiosyncratic to the interbank market (including extraordinary liquidity assistance, ELA, and banks' balance sheet shrinkage exercises). This structure motivates a structural model that contributes to improved interpretation of a VARMA empirical model. This complex combination of effects cannot easily be handled in a standard VAR analysis and this motivates a more tailored approach discussed below.

[8] There may also be some significance in the fact that the role of money was de-emphasized by the ECB in its May 2003 statement on monetary policy strategy after which we observe a general rise in repo market activiy (see, Berger, de Haan and Sturm 2011 for a discussion and analysis of this change).

3.1 Pre-Crisis VAR Modelling

The initial focus of our pre-crisis analysis is the interaction between the repo market and auctions controlling for anticipation of rate changes and activity elsewhere. We test for Granger causality by the application of block-exogeneity tests. The following array of variables, denoted as "X", is modelled in the pre-crisis VAR-ECM (where superscripts indicate the venue of the variable and dots imply first-differences); $X = \{\dot{Q}^{repo}, P^{repo}, \dot{D}^{auc}, P^{auc}, \dot{Q}^{eonia}, P^{eonia}\}$. The non-rate variables are transformed to logs before differencing and all non-auction variables are weighted daily averages for the days between weekly MRO auctions. Q denotes volume traded, P is the interest rate in the respective trading venue/auction as a deviation from the ECB's target rate and D is an auction excess-demand variable or more specifically, the sum of unallocated bids in auctions as reported by the ECB soon after the auctions.[9]

We add a number of control variables, denoted "Z" below, as follows; $Z = \{YEND, MPP_i, LTR, t, ESWAP, V1X, ECM, \dot{Q}^{eurex}, P^{eurex}\}$. $YEND$ is a dummy variables for each of the first and last three inter-auction periods of the year, MPP_i are dummy variables for each of the first two and last two weeks of each maintenance period, LTR is the volume of funding in place from longer term ECB operations, t is a time trend, $ESWAP$ is the difference between the 1-month EONIA swap rate and the EONIA rate (this is to capture expectations about rate changes - and follows the practice in Mancini et al., 2013), $V1X$ is a volatility index for the European market - analogous to the VIX in the US; the ECM variable is an error correction term associated with the cointegrating relation between Q^{repo} and M^{repo} where M denotes the amounts maturing on previous repo contracts. In addition to these controls the modelling of $\dot{Q}^{repo}$ requires that we include lags of $\dot{M}^{repo}$ to make it an ECM representation. The final two controls are for activity and pricing in the EUREX repo market ($\dot{Q}^{eurex}$, P^{eurex}). We would have included the EUREX trade volume and price on both sides of the VAR but the EUREX platform did not exist for most of the pre-Crisis sample.

We employ a simple two-step approach to cointegration which is only relevant for the

[9] Bids are allocated in accordance with the declining magnitude of bid prices until all of the planned allotment is spent...so the bids without allocations could generate demand for funding in the interbank market after the auction or in the next auction and it could explain some of the fluctuation in aggressiveness of future bidding.

first variable in X (i.e., in the case of the volume of repo activity, Q^{repo}, and maturing amounts from earlier contracts, M^{repo} - see Engle and Granger, 1987). This makes it easier to test different combinations of the variables in the VAR system as a whole. While it is true that the three main volume variables - EONIA, EUREX and BrokerTec - are all non-stationary there are no significant cointegrating relations in the permutations of this set. In the case of EONIA and EUREX markets we assume that the maturing amounts roughly equals the amount traded the previous day (i.e., overnight contracts maturing) so we use their first-difference in the analysis. The repo, EUREX and EONIA **rates**, denoted above as P^{repo}, P^{eurex} and P^{eonia}, are all stationary in the pre-crisis period so we model them as deviations from the ECB target rate.[10]

There is an argument for focusing on relations between variables strictly within maintenance periods (MP) since reserve averaging involves constraints on behaviour within these periods. However, our focus is on a broader category of behaviour beyond such reserve management constraints. These would include adjustments in behaviour by banks that learnt something from previous auction results/allocations about how optimal their own bidding behaviour had been in the past; and about the relative merits of where they tapped liquidity before. It includes banks' assessments about liquidity conditions in the repo market based on their experiences while trading in previous maintenance periods. Based on our strong priors about the need to separate "within" and "across" maintenance period effects, we accommodate intra- and inter-maintenance period seasonality by the inclusion of a one-period lag and a fifth-period lag of all variables in the VAR. Previous analysis shows that most of the explanatory power in these regressions is captured by the first lag. The AR(1) parameters mostly apply to "within" MP feedback effects (with the 1st lag only crossing over to an earlier maintenance period approximately once-in-every-five cases). We are deliberately avoiding the inclusion of lags from 2 to 4 since these increasingly involve a mixture of within- and across-MP effects that are difficult to interpret. The fifth lag, approximately, implies a MP-on-MP effect. Maintenance period level-effects are captured by the inclusion of the MPP dummy variables above.[11]

[10]We have omitted presentation of the stationarity and cointegration testing as they are not surprising and detract from the main focus of our analysis. These test statistics are available from the authors on request.

[11]In an earlier version of this paper we employed interactive dummy variables to more accurately capture the maintenance period effects but this led to a large loss in precision of estimates because many more

The VAR-ECM outlined above has the following form; $X_t = A_0X_t+A_1X_{t-1}+A_5X_{t-5}+B_0Z_t+B_1Z_{t-1}+B_2Z_{t-5}$ where the A_0 and B_0 parameter matrices contain zeros everywhere except where the association implies a relation between an auction variable and a non-auction variable (since auctions take place almost instantaneously at the end of each period they can be modelled in relation to everything that happened within period 't').

In addition to block-causality analysis - which is mainly about the interaction between liquidity provision and interbank markets - we use the above model to assess the effects of interest rate changes on each of the variables in the VAR-ECM by including dummy variables for each of the five weeks that precede and follow an interest rate change (these are all positive innovations in the targeted interest rate in the two years preceding the crisis).[12] The successive cumulative sum of the parameters estimates on these event dummies are tested for significance. We tabulate the parameter estimates and their significance and also depict the point estimates of the accumulated pre- and post-event effects with their standard error bands. The results lead to a discussion about the nature of the transmission mechanism through which interest rate policy acts. If interest rate policy directly drives the smooth functioning of the interbank market then there are limits to its effectiveness more generally.

3.2 Crisis-Period Modelling

A VAR approach cannot easily be applied to assess interactions in the crisis regimes because there are too many sources of extreme shocks to both the auction and repo markets. However we appeal to a different specification that more effectively isolates the effects of innovations in auction behaviour (and allotment policy) on interbank market activity. Since our focus is on how the auction innovations feedback on the interbank market there is some advantage from directly isolating these innovations. This model is more relevant for the first crisis regime but we will apply it to both the pre- and post-Lehman crisis regimes showing that causality (in either direction) breaks down once fixed-rate full-allotment auctions are introduced. The model can be identified with fewer parameters than a standard

parameters were introduced. The findings indicated that maintenance period seasonality is usually insignificant in the pre-crisis sample. The more parsimonious model adopted above is a compromise that trades off accurately capturing the maintenance period seasonality and loss of statistical significance.

[12] There were eight ECB interest rate increases between November 2005 and May 2007.

VAR and it helps with interpretation of the types of feedback that come from auction behaviour and policy changes. The associated empirical strategy (which is approximately a VARMA representation) is based directly on this plausible structural interpretation of the interactions between repo market crisis effects and auction policy responses (inclusive of innovations in auction bidding behaviour).

We now consider how unobserved effects can be identified from an empirical representation of auction and repo market interactions during the first crisis regime. We start with the fact that we can directly observe the outcomes from both auctions (specifically, allotment innovations and bidding aggressiveness in the form of a larger spread between the weighted average settlement rate and the policy target) and from interbank activity (i.e., the extent of the sharing of liquidity and collateral through trading). We also observe variables indicating changes in counterparty quality, risk aversion, hoarding of liquidity and collateral, and changes in collateral quality (i.e., bank and sovereign CDS spreads and microstructure variables such as bid-ask spread and depth of the limit order book from the repo market). However, the auction and interbank variables are jointly determined and have a complex dynamic relation with each other. The history of past innovations in auction allotment, bidding behaviour and interbank market dislocations are accumulated such that each observed variable is a mixture of effects. The settlement rate and trading activity are endogeneous but we assume that, for the frequency of our analysis, the previously observed CDS spreads and the microstructure indicators can be considered as exogenous.

In the present context it is possible to directly assess the effects of the auction-related structural innovations on interbank repo activity by including a lagged residual from the auction equation in the repo equation. The structural model we now outline gives rise to a partial VARMA specification that is an alternative to the VAR empirical approach and enables a more direct and tractable assessment of auction effects on interbank market activity under the constraints just described. It is also restrictive enough to avoid identification issues often associated with generalized VARMA modelling (see, for example, Lütkepohl, 2005).

We assume that auction price and quantity (P^{auc} and/or Q^{auc}) respond to developments in the interbank market - which we represent as Q^{auc}. The cumulative response can be represented by a random walk, $W_t = W_{t-1} + \omega_t$, which is common to the auction and interbank variables. These common effects come from the substitutability of locating reserves in the two venues. A relatively high price in auctions will usually cause a rise in the quantity conducted in the interbank market (controlling for other effects). A higher supply at auctions will usually involve reduced need for interbank activity. These effects are assumed to be approximated by a random walk during the first crisis regime because they involved accumulation of unpredictable innovations.[13]

We assume that the interbank market is the location where crisis effects enter the reserve management and liquidity sharing system. Crisis effects are assumed to be related to counterparty and credit risk developments as well as a range of other occurrences (e.g., direct state funding through ELA or asset and liability shrinkage exercises by banks) and we denote these as a random walk process $Z_t = Z_{t-1} + \zeta_t$. We will define this component in such a way that positive innovations represent an improvement in risk - and other structural conditions - so that Z_t enters with a positive sign in the interbank market equation (ceteris paribus). The interbank market is also affected by past auction allotment policy and bidding behaviour (the sign on this will depend on whether we are referring to the P^{auc} or Q^{auc} variable). The interbank market can be written as follows (where η_t is an additional noise term);

$$Q_t^{repo} = b_0 \quad + \quad b_1 W_{t-1} + Z_t + \eta_t \tag{1}$$

$$\begin{aligned} \text{where... } W_t &= W_{t-1} + \omega_t \\ Z_t &= Z_{t-1} + \zeta_t \\ \omega_t &\sim iid(0, \sigma_\omega^2) \\ \zeta_t &\sim iid(0, \sigma_\zeta^2) \\ \eta_t &\sim iid(0, \sigma_\eta^2) \end{aligned} \tag{2}$$

Consider now the auction equations (for convenience we depict the case of the weighted average settlement rate, P^{auc}, but the case of Q^{auc} is analogous). The auction can be

[13] These innovations can be interpreted as the unpredictable changes in the auctioneer's choice between allowing the weighted average settlement rate to diverge from the policy target rate and maintaining the supply of reserves close to the reserve requirement of the banking system.

described as having components related to the cumulative auction allotment policy changes (and cumulative changes in bidding behaviour) as well as the accumulated feedback that previous auctions had on the interbank market. The auction equation is therefore as follows (where μ_t is an additional noise term);

$$P_t^{auc} = a_0 \quad + \quad W_t - a_1(b_1 W_{t-1} + Z_t + \eta_t) + \mu_t \tag{3}$$

$$\text{where... } \mu_t \quad \sim \quad iid(0, \sigma_\mu^2)$$

Substitution of the interbank market activity variable, Q^{repo}, into the auction equation will result in the following;

$$P_t^{auc} = a_0 + \ W_t - a_1 Q_t^{auc} + \mu_t \tag{4}$$

If Z_t was observable we could subtract it directly from the auction equation and the model would be fully identified and a separation of the auction contribution to the interbank market could be measured. Since Z_t is a permanent component it could be estimated by calculating the long run effect of idiosyncratic random walk shocks in the interbank equation as described in Beveridge and Nelson(1982). However, this also requires that W_{t-1} is identified in the interbank equation. Since this is not directly possible we consider a different approach to identifying the components. Differencing the terms in both equations results in the following model (where we use dot notation to indicate a differenced variable or, more specifically, either the percentage roll-over relative to maturing repos or the excess or shortfall in allotment relative to amounts from maturing operations).

$$\begin{aligned} \text{Auction difference equation: } \dot{P}_t^{auc} &= \dot{W}_t - a_1 \dot{Q}_t^{repo} \\ &\quad +\mu_t - \mu_{t-1} \\ \text{Interbank difference equation: } \dot{Q}_t^{repo} &= b_1 \dot{W}_{t-1} + \dot{Z}_t + \eta_t - \eta_{t-1}. \end{aligned} \tag{5}$$

Further simplification results in the following;

$$\begin{aligned} \text{Auction difference equation: } \dot{P}_t^{auc} &= -a_1 \dot{Q}_t^{repo} + \omega_t \\ &\quad + \mu_t - \mu_{t-1} \\ \text{Interbank difference equation: } \dot{Q}_t^{repo} &= b_1 \omega_{t-1} + \zeta_t + \eta_t - \eta_{t-1}. \end{aligned} \tag{6}$$

One useful outcome from these manipulations is that it shows that the auction equation can be estimated with an MA(1) error process $e_t + \phi e_{t-1} \approx \omega_t + \mu_t - \mu_{t-1}$. We note that ω_t is a prominent component of this error process but unfortunately it is combined with a noise term (there is also a possibility that ω_t is correlated with ζ_t but we leave examination of this until a robustness analysis is done). The interbank market equation can also be represented as an MA(1) which features the lagged auction innovation ω_{t-1}. It would be useful if a measure of ω_{t-1} was available to include separately in this equation. We therefore consider whether the error e_{t-1} from the auction equation, which is likely to be highly correlated with ω_{t-1}, could be used to good effect in the repo market equation when it is combined with other variables that capture developments in the interbank market. Suppose we have variables, denoted h_t, that capture innovations in banks' counterparty risk, changes in collateral quality and/or other measures of changes in the efficiency with which interbank borrowing and lending can be achieved. These variables are likely to be correlated with ζ_t and η_t and uncorrelated with ω_t (we assume that the monetary policy auctioneer is not monitoring the interbank market and responds with a lag to developments there - this seems to be a good description of what was happening during this part of the crisis according to the presence of surprise bidding aggressiveness in the auctions as described by Drehmann and Nikolaou 2009). These variables could therefore be used to control for interbank idiosyncratic effects in the following empirical model;

$$\begin{aligned} \text{Auction difference equation: } \dot{P}_t^{auc} &= -\hat{a}_1 \dot{Q}_t^{repo} + e_t + \phi e_{t-1} \\ \text{Interbank difference equation: } \dot{Q}_t^{repo} &= \hat{b}_1 e_{t-1} + \hat{b}_2 h_t + v_t + \pi v_{t-1}. \end{aligned} \tag{7}$$

The coefficient on the lagged auction equation residual $\hat{b}_1$ should therefore represent the contribution of ω_{t-1} to stabilizing or harming the sharing of funding in the interbank market. We can test this parameter for statistical significance in order to test whether there is a role for allotment policy and auction bidding behaviour in affecting the interbank market. The inclusion of h_t should lead to a reduction in the significance of the MA(1) coefficient in the interbank equation. This can be used as a test of whether the controls are effective. The improvement in the fit of the interbank equation when the lagged residuals from the auction equation are added provides a measure of the size of the contribution from auction effects on interbank activity.

The steps of this empirical strategy can be summarized as follows;

1. Regress $\dot{Q}^{auc}$ (and do the same for $\dot{P}^{auc}$ in the Variable Rate Auction crisis period) on $\dot{Q}^{repo}$ and include MA terms.
2. Collect the lagged residuals from this (or each of these) model(s).
3. Regress $\dot{Q}^{repo}$ on the lagged collected residuals and include MA terms.
4. Test the significance of the added residuals. This is potential evidence of the presence of an auction effect. The sign of this effect will reveal whether price or quantity effects are stronger (it seems more likely that there would be a negative parameter on the quantity equation residuals).
5. Test the joint significance of any included MA terms. If these are significant this is interpreted as evidence of the presence of endogenous effects in the added residuals.
6. Add controls for changes in counterparty risk, collateral quality and interbank market microstructure indicators to the regression of step 3.
7. Test for significance of the added controls. Significance signifies that endogeneity has been controlled for (although this, on its own, is not sufficient for such a conclusion).
8. Test for significance of the MA terms. If MA terms become insignificant when the controls are added this provides further evidence that endogeneity has been almost surely controlled for.
9. Re-test for significance of the added residuals. If they remain significant while controls are significant and MA terms are insignificant then this is interpreted as strong evidence of an auction effect.

In the case of the first crisis period both the settlement rate, P^{auc}, and the quantity allotted, Q^{auc}, are relevant indicators of auction policy and behaviour. We therefore run these two regressions separately and we use the lagged residuals from both auction regressions in the interbank regression. In this way we can ascertain whether increased overall allotment quantity or the more targeted allocation of auction funding due to bidding aggressiveness was most important in affecting the interbank market. In the second crisis period (when fixed-rate full allotment applies) we revert to just one auction regression which concerns auction allotment, Q^{auc}.

We estimate the above model using various candidates for the set $\{h_t\}$, such as indexes of country-specific bank CDS spreads (specifically log(CDS)), sovereign debt CDS spreads, the Euribor-OIS spread and microstructure variables from the interbank market such as innovations in bid-ask spreads and changes in market depth. In the second crisis period there is less reliable data for CDS spreads and we therefore rely on repo market microstructure variables alone.

4 Data

4.1 ECB Auction Data

Until October 2008 all ECB operations were done by way of competitive auctions in which a planned quantity of liquidity was allocated firstly to the best bidder(s) and then to progressively lower bids until all the planned (and announced) allotment amount was exhausted (on a discriminating price auction basis). Monetary policy operations during the crisis involved a number of very different approaches by the ECB to mitigate the effects of the financial turmoil. In the pre-Lehman 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 'benchmark allotment' (this was front-loaded near the early part of the maintenance period) while still aiming for balanced liquidity conditions at the end of the maintenance periods, (2) extending the average maturity of its financing by use of Supplementary LTROs (SLTROs), and (3), engaging with other central banks to relieve liquidity shortages of euro area banks in other currencies (mostly US dollars as extensions of the TAF operations).

When crisis-related stresses within the interbank market were escalated by Lehman's failure, 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[14], (3) increased the range of assets eligible for use as collateral in Eurosystem credit operations[15] and (4) increased US dollar swap financing by use of fixed-rate tenders with full allotment by special arrangements with the Federal Reserve System.

In the period from 2010 policy became even more accommodating in the context of the sovereign debt crises that occurred in peripheral euro area countries. This led to further relaxations in the type and quality of collateral that could be used in official operations[16], various asset market intervention programmes (including two Covered Bond Purchase Programmes and the Securities Markets Programme), extension of fixed-rate full-allotment auctions, introduction of a number of supplementary long-term operations (including the three year operations announced at the end of 2011) and a halving of the required reserves ratio to 1% of applicable liabilities in December 2011.

These changes are largely visible in sovereign yield spreads and to some extent in measures of counterparty risk. The speech by Mario Draghi in London in July 2012 made a commitment to defend against a euro break-up that was perceived as contributing to the excessive elevation of peripheral sovereign bond yield spreads. Soon after the speech the OMT (Outright Monetary Transactions) programme was announced and, although the policy was not implemented, the demonstration of policy resolve had a persistent calming effect on markets and reduced sovereign yield spreads through the end of our sample period. It is also possible that the acceptance of poorer quality collateral in ECB operations led to improved quality of collateral among a smaller group of relatively high-quality banks within the interbank market. These effects are difficult to untangle and since we only have

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

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

[16] Some widening of the type of acceptable collateral was initially combined with restrictions on quality. Quality restrictions were imposed on asset backed security collateral in November 2009. There was a relaxation in the quality of acceptable sovereign collateral when Greek bonds were declared acceptable despite a reduced credit rating in May 2010 and this was extended to Irish sovereign collateral in March 2011 and to Portuguese collateral in July 2011. Collateral rules were eased further in December 2011, see `http://www.ecb.int/press/pr/date/2011/html/pr111208_1.en.html` for details.

access to interbank repos based on sovereign collateral we concentrate on CDS spreads (sovereign and banking sector) as the main harbingers of counterparty and collateral quality developments and we leave more detailed collateral analysis for future work.

The auction data used in our analysis is available on the ECB's website. There are a range of auction outcomes that are reported soon after auctions take place. The most relevant variables for our analysis relate to the settlement rate and the quantity allotted. Many of the other auction variables are correlated with these (e.g., unsatisfied demand and number of bidding banks). We therefore focus on the rate and/or quantity outcomes from auctions depending on the sample studied.

4.1.1 Settlement Rate

There are two settlement rates that are reported after auctions. One is the marginal rate and the other is the weighted average rate. The marginal rate is the lowest rate at which auction allocation is exhausted. The weighted average rate is the weighted sum of all the bid rates at which allocations are made where weights are the proportion of total allocation that is made at each bid rate. These two price outcomes are positively correlated but the weighted average rate tends to be more variable and, in our view, contains more information about the aggressiveness of bidding in auctions. We therefore use the weighted average rate as the basis for the auction rate variable in our regression analysis. Since this rate is non-stationary in the first crisis period, we transform it by taking the percentage change in the weighted average rate relative to the rate charged by the ECB on its marginal lending facility (this closely tracks the ECB target rate but it is usually around 1 whole percentage point above the target rate). Figure 1 shows a plot of the excess weighted average settlement rate and its change relative to the lending rate.

The deviation of the weighted average settlement rate from the ECB's target marginal rate widens at points of acute stress during the early part of the crisis and is at its maximum around the Lehman event. This is indicative of the level of banks' aversion to liquidity shortfalls and also of the reluctance of the ECB to provide funding in excess of what was planned. It is known that during the variable rate auction phase of the crisis, some participants were more desperate to ensure allocation at auctions and submitted bids at much higher rates than the target marginal rate (this is described in Drehmann et al., 2009).[17]

4.1.2 Auction Supply & Outstanding Liquidity

In normal times, the amount allotted through ECB auctions is very similar to the amount maturing from a previous auction. However, during the pre-Lehman crisis period there was a degree of flexibility in allotment quantity and this is of interest in our analysis. Also, during the post-Lehman period there was a fixed rate and a completely variable allotment quantity. We therefore construct an auction supply shock variable that is based on the difference between allotment and the amount maturing from a similar previous auction (i.e., a percentage excess relative to amounts maturing). These level and innovations series are shown in Figure 2.

In the pre-crisis period, refinancing operations of the ECB were very stable with around 300 billion euro 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, allotment and demand at LTRO was stable and usually involved outstanding repo lending by the ECB of about 100 billion euro (also planned to replace maturing operations). In the last quarter of 2008 allotment in MROs declined to achieve about 150 billion euro outstanding and this facilitated an increase in the supplementary longer term operations (SLTROs). SLTROs were of increasingly longer duration and new supply in these operations was more than replacing what was maturing from previous operations.

The two 3-year operations conducted at the end of 2011 and early 2012 pushed the outstanding liquidity supplied through MRO and LTRO operations to almost 1.4 trillion euro. The outstanding liquidity associated with LTRO and MRO operations is shown in Figure 3. The introduction of the 3 year operations was a major break with normal operations in terms of supply. These increases were, to a significant extent, matched by increases in the amounts deposited with the ECB. This indicates a precautionary motive

[17] Drehmann and Nikolaou (2009, 2013) use the aggressiveness of bidding behaviour of banks in Main Refinancing Operations (MROs) as an indication of their "funding liquidity risk aversion." The deviation between the intended policy target rate and the weighted average rate obtained by participants in official operations is a close substitute for their measure and is indicative of variation in liquidity needs not satisfied in the interbank market.

for accessing ECB liquidity at the longer term operations in order to fund possible future demand shocks.

4.2 Euro-Area Interbank Repo Markets & Repo Data

The European Repo Council's (ICMA) biannual survey of European repo trading reveals that traded repo volume grew at a rate of roughly 20% each year between June 2001 and June 2007, reaching a high point of 6,504 bln EUR in June 2007.[18] It declined to 4,633 bln EUR in December 2008 after the financial crisis hit before recovering to 6,885 bln EUR in June 2010; it then declined again to 5,611 bln in December 2012. Almost 60% of repos declared in the ICMA survey are based on euro denominated government bonds but the survey notes indicate that there is a degree of double counting of this volume (about 20% of trades are likely repeated records in the case of repos using euro area sovereign collateral).

4.2.1 Interbank Repo Market Data

Our analysis is based on the volume of repos traded on the BrokerTec Inter-Dealer Trading Platform using euro area sovereign collateral. We use the daily average of volume over the days between auctions. Activity on BrokerTec's repo trading platform in sovereign backed repos largely reflects a similar pattern to the ICMA survey of all euro area repo volume over time.[19] We estimate that BrokerTec accounts for up to 17% of all trading in repos using euro area sovereigns and approximately 50% of the automated trading system (ATS) traded volume of such repos.[20]

Figure 4 displays the time series of ICMA reported volume and the daily volume traded on BrokerTec. Both series display a secular increase throughout the pre-crisis period. There

[18]The interbank repo market in Europe is surveyed on a semi-annual basis by the European Repo Council of the International Capital Market Association (ICMA). 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. The latest survey is posted here:`http://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/short-term-markets/Repo-Markets/repo/latest/`

[19]Trading in Italian repos is mostly conducted on the MTS platform. The other venue that has a significant share of repo trading is the Eurex exchange and the characteristics of this repo activity is studied in detail by Mancini, Ranaldo and Wramplemeyer (2013).

[20]The combined volume of repo activity conducted on BrokerTec and MTS is available at `http://www.repofundsrate.com/`.

is a high degree of consistency between BrokerTec volume and the overall volume of activity in repo markets revealed in the ICMA survey results. Between the start of the interbank market disruptions of 2007 and the Lehman collapse in October 2008 there was a sharp downward trend in daily volume traded on BrokerTec (falling from 350 bln to about 250 bln). Soon after the Lehman collapse there was an increase in activity for a while and, apart from some significant temporary declines around the times of the Greek and Irish sovereign debt crises, there was a general improvement in activity up until late summer 2011 when there was significant contagion to Spanish, Portuguese and Italian sovereign debt markets. Mid-way through the second quarter of 2012, BrokerTec trading activity had returned to its pre-crisis highs of about 400 bln in daily volume. Activity declined again during the euro (break-up) crisis of the summer of 2012 until (ECB president) Mario Draghi's comments reversed sentiment in late July. Activity has remained high on average since then but with increased variability.

The volume traded is interesting in itself, but for the purposes of our analysis we use the average daily volume traded and the average daily volume maturing based on all previous repos traded on the BrokerTec platform. The excess of new volume relative to that maturing is shown in Figure 5. This behaves like a first difference of the total volume traded but this construct avoids introducing complex moving average dynamics due to variation in the maturity of the previous day's trades. To make this data transformation it is necessary to track the maturing trades from the past. Fortunately, the trade-by-trade data supplied by ICAP includes the term of contracts so this transformation of the data is possible with limited error. To account for the fact that some trades that mature early in the sample are not observable because they were contracted before the start of our sample, we use the first six months of the sample to generate the first data point used in the analysis. We use a comprehensive set of sovereign repo contracts in our analysis. The data supplied by ICAP covers a wide range of specific and general repo contracts associated with collateral issued by almost all euro area sovereigns and for various terms to maturity. A relatively large proportion of all activity on BrokerTec is associated with repo contracts that use named collateral but these are done at rates that differ only slightly from general collateral rates and we therefore include them in our analysis.

The depth and spread control variables used in the regression analysis below are based on the series displayed in Figure 6 and Figure 7. These variables were measured for each individual market by repo collateral and term. The daily time weighted averages of individual contracts were averaged across the contracts associated with country-specific collateral to get the relevant country measure.

4.2.2 Sovereign and Bank CDS Data

The CDS spread variables were obtained from a Bloomberg source of Markit data. All available bank-specific CDS contracts, for the main banks within each country included in our analysis, that insures credit default on senior bonds at a 5 year maturity were collected at the end of each trading day. CDS premiums on sovereign bonds of 5 year maturity were similarly collated. Country-level bank CDS indexes were calculated as a simple average of the bank-specific CDS premiums. We take the daily average of the log change in the various CDS premiums/indexes for the days between auctions.

5 Empirical Results and Interpretation of Results

5.1 Results: Pre-Crisis VAR

Tables 1(a), 1(b) and 1(c) follow the VAR-ECM structure discussed in Section 3. In each case we show results for an unrestricted estimation and those for a model which omits all parameters that can be jointly rejected as significant. Overall, the estimates have intuitive appeal and there is a high proportion of variation in the dependent variables explained by the regressions. We found only small amounts of auto-correlation in the residuals and all standard errors are Eiker-White (heteroscedasticity and serial correlation consistent) standard errors.

Table 1(a) shows the results for the case where the dependent variables are respectively, the percentage change in repo market volume $\dot{Q}^{repo}$ and the repo market rate P^{repo}. In all 4 regressions the control variable representing interest rate expectations, E^{swap}, and the ECM term (i.e., the lagged residual from the relation between the level of Q^{repo} and the level of maturing amounts M^{repo}) are always statistically significant. The change in the $\bar{R}^2$ when these two variables are dropped - in the case of the unrestricted regressions - is 7% and 48% respectively where the full unrestricted models have $\bar{R}^2$ of 0.54 and 0.61 respectively. Thus, both variables are important and the expectation of interest rate changes is of particular importance for the repo market rate. It is notable from Table 1(a) that many of the coefficients are insignificant in the unrestricted regressions (12 variables can be dropped from the $\dot{Q}$ regression with little effect on the overall fit and 16 can be dropped from the P regression). There is little role for MP-on-MP effects in the case of $\dot{Q}$ with only one parameter at lag 5 surviving the insignificance cull.

We are particularly interested in assessing whether the results of behaviour in ECB auctions has any relevance for the repo market. A joint test of the significance of the first and fifth lags of D^{auc} and P^{auc} is marginally rejected despite the individual statistical significance of D^{auc}. The join test of the 4 coefficients involving D^{auc} and P^{auc} has an F-statistic of 1.6145 and an associated p-value of 0.167. Whether these variables are jointly able to account for much of the explained variation in $\dot{Q}^{repo}$ is a relevant question if monetary policy operations are to have some control over developments in money markets. There is a rise in the $\bar{R}^2$ when these 4 variables are dropped from the unrestricted regression and, in the case of the restricted regression there is only a fall in the $\bar{R}^2$ of 0.007 when the D^{auc} variable is dropped. So, there is not much evidence of an interaction between official operations and interbank activity in the repo market. This is despite the fact that the empirical specification overall - including a role for risk represented by the V1X - explains a lot of the change in repo market activity (so the absence of a relation does not seem to be due to unreliability of the repo market volume data).

Auction related variables are somewhat more relevant for the dynamics of the repo market rate P^{repo}. The join test of the 4 coefficients involving D^{auc} and P^{auc} in the unrestricted regression has an F-statistic of 2.043 and an associated p-value of 0.085. The drop in the $\bar{R}^2$ when these 4 variables are dropped from the unrestricted regression is only one-fifth of 1 percent. When the two auction variables are dropped from the restricted regression (the last column of Table 1(a)) the $\bar{R}^2$ drops by 0.014. This again indicates that auction variables do not appear to be strongly causal for the interbank market repo rate.

Another issue of interest concerns whether there are any strong substitution effects between the interbank repo market and the unsecured market (EONIA) or the GC-Pooling market (EUREX). The EONIA rate - lag 1 - and the EUREX volume - lag 5 - both remain significant in the restricted model for Q^{repo} and the EONIA volume - lag 1 - and EUREX rate - lag 5 - remain significant in the restricted model for P^{repo}. Dropping these variables causes the $\bar{R}^2$ to fall by 0.014 and 0.0045 in the Q^{repo} and P^{repo} retricted models respectively. So there are significant but small substitution effects at work between these markets.

Table 1(b) shows the results for the case where the dependent variables are respectively, the percentage excess demand in auctions (i.e., amounts bid for in excess of amounts allocated as a % of allocated amount) D^{auc}, and the weighted average settlement rate in auctions, P^{auc}. These regressions include period 't' variables because the auction only occurs at the very end of the week (almost instantly). There is not a lot of variation in the P^{auc} and a large proportion of this is explained by the regression.

Once again, in all 4 regressions the control variables representing interest rate expectations, E^{swap}, and the ECM term have some presence (and the V1X remains relevant in the D^{auc} restricted model). Dropping E^{swap} reduces the $\bar{R}^2$ by 0.0105 and 0.01375 in the case of the D^{auc} and P^{auc} restricted models respectively. So, interest rate expectations do not appear so relevant to bidding aggression at auctions (this is probably because auction behaviour is dictated by within maintenance period liquidity management and there never interest rate changes during a maintenance period).

As before, many variables in the unrestricted model are insignificant with 6 out of 30 surviving the cull in the case of D^{auc} and 9 out of 30 surviving in the case of P^{auc}. Since most of the variables dropped involve cross-effects from other markets (repo, EONIA and EUREX) this is a first indication that there are very weak spill-over effects from these markets to auction behaviour. To assess this more accurately we must also consider the remaining significant parameters involving such cross-effects in the restricted regressions. In the case of the D^{auc} restricted regression the P^{repo} variables remains significant but no EONIA or EUREX variables are significant. However, in the case of the P^{auc} restricted regression the $\dot{Q}^{repo}$ - lag 1 -, P^{repo} - lag 0 -, $\dot{Q}^{eonia}$ - lag 0 -, $\dot{Q}^{eurex}$ - lags 1 and 5 -, all remain individually significant. Dropping these cross-effects reduces the $\bar{R}^2$ by 0.024 and 0.030 in the case of the D^{auc} and P^{auc} restricted models respectively (the F-test for these variables being irrelevant for the P^{auc} restricted model is 5.855 with a p-value of ¡0.0001). Overall these cross effects are very statistically significant but not substantial in size.

Table 1(c) involves the EONIA volume and rate as dependent variables. These results have a similarity with those of Table 1(a). Firstly, the control variable for interest rate expectations is important particularly for the EONIA rate. The change in the $\bar{R}^2$ when the EONIA-Swap variables is dropped from the P^{eonia} restricted equation is 0.48256. Thus, the expectation of interest rate changes is of particular importance for the EONIA market rate (as was the case for the repo rate).

Again, we are interested in assessing whether the results of behaviour in ECB auctions has any relevance for the EONIA market. In the case of the P^{eonia} restricted regression there is only a slight fall in the $\bar{R}^2$ of 0.00324 when the P^{auc} - lag 5 -variable is dropped. So, there is not much evidence of an interaction between official operations and EONIA pricing. This is despite the fact that the empirical specification overall explains around 60% of the variation in the dependent variable. Cross effects between the different venues again do not look substantial despite their statistical significance.

5.1.1 Interest rate events

We include dummy variables for each of the five weeks preceding and following 8 interest rate events (these occurred between November 2005 and Juny 2007). We use these to construct a Cumulative Average Abnormal Response (CAAR) analysis (the coefficients are summed from the event to each of the pre-event and post event dates and standard errors are calculated for these sums). We show the results of the CAAR analysis in Figure 8 for the 6 equations of the VAR. These indicate significant effects in most cases. Specifically, repo market activity is higher than usual in advance of the rate rises and lower than usual after the rate rises. Although we have included a control variable for anticipation of the rate moves, this is consistent with agents substituting activity towards the period with the lower rate. The repo market rate is also significantly elevated before the rate rise and stabilises after the event. This is consistent with a smooth transition to the higher rate.

The middle section of Figure 8 is associated with behaviour in the 5 auctions before and after the rate rises. The plot in the middle left-hand panel shows that excess demand in auctions was significantly below its usual level before and after the rate rises (it peaks at the same time as the rate rise). This most likely reflects a smaller actual demand expressed in these auctions. The middle right-hand panel also reveals that bidding aggressiveness in the auctions was more subdued the further one goes from the the time of the rate rises. This may be reflecting more reliance on other venues at these times.

The last two plots in Figure 8 refer to EONIA activity and rate. This shows some evidence of an elevated level of activity in advance of the rate events but no significant deviation from normal after the events. The EONIA rate behaves very like the repo-market rate, being elevated before the rate rise and stable afterwards. Overall, these rate rises had a large impact on behaviour in the interbank markets. We would regard these effects as too immediate and large to be a reflection of a behavioural response in consumption and investment feeding through to reduced transactions demand for liquidity.

We can assess the size of these effects by examining the change in the $\bar{R}^2$ when the event dummies are dropped from the respective regressions. When the event dummies are dropped the $\bar{R}^2$ drops by only 0.006 in the $\dot{Q}^{repo}$ restricted regression. The decline in fit is 0.065 for the P^{repo} restricted regression. For the D^{auc} restricted regression the decline in fit is 0.034. There is a very slight change in the $\bar{R}^2$ of 0.003 for the case of the P^{auc} restricted regression. The explained variation in the last two regressions, $\dot{Q}^{eonia}$ and P^{eonia}, decline by 0.020 and 0.087 repectively. These effects are economically significant for the rates in both the BrokerTec repo market and the EONIA market. While the effects are not large for the volume of activity, these are comparable to the effects of liquidity providing operations. Auction behaviour seems to be mostly affected in terms of the overall demand in auctions.

5.2 Results: Crisis Periods

Table 2 contains combined auction regression results for the first and second phases of the financial crisis. The Crisis I period ends just before the Lehman event and the Crisis II sample begins with the introduction of fixed rate full allotment auction (which was soon after the Lehman event). Regressions (1) to (3) concern the weighted average settlement rate as the dependent variable. The goodness of fit, $\bar{R}^2$, is 13% for regression (2) which was the model that we selected as a source of residuals for the supplementary regression. The main result of interest here is the significant negative coefficient on recent repo market average daily volume. A higher than normal volume is associated with reduced aggressiveness of bidding in the auction that follows. This is consistent with the assertion that good sharing of liquidity within the repo market reduces the urgency by rationed banks to obtain funding at auctions. Other notable aspects of the first three regressions include a strong turn-of-year effect and a residual that does not have a significant MA(1) coefficient as would have been consistent with our structural model. By reference to equation (3) above we see that this implies an insignificant shared transitory component in the structural model. We note that this does not rule out an MA(1) structure for the supplementary regression and there remains a role for the lagged residual from the auction regression in the supplementary regression.

Regressions (4) to (6) concern the excess auction allotment relative to maturing amounts from a previous similar auction as the dependent variable. The goodness of fit, $\bar{R}^2$, is roughly 47% in these cases. The test of exclusions does not support a move from regression (4) to (6) and we selected regression (5) as a source of residuals for the supplementary regression (the results of the supplementary regression are not sensitive to this selection). There is a negative coefficient on recent repo market average daily volume in these regressions but the coefficient estimate is never statistically significant. If the ECB wants to avoid a divergence in the marginal settlement rate from the intended policy rate then we would expect allotment to increase if aggressive bidding in the auctions becomes widespread among participating banks. If aggressive bidding is widespread, the originally intended allotment quantity will be used up before the marginal rate declines to the policy target. On this basis we would expect a positive relationship between aggressive bidding (the weighted average settlement rate) and the allotment innovations. We would also therefore expect a negative coefficient on the allotment innovations and repo market trading activity. The sign of the coefficient on repo volume in regressions (4) to (6) is negative as expected but insignificant.

Regressions (4) to (6) also include a large and significant turn-of-year effect and an end-of-maintenance period effect (the *Last* dummy variable allows a different level effect in the last operation of the maintenance period). The coefficient on the dummy variable indicating that the previous operation was an LTRO auction, ($LTRO_{t-1}$), is also significantly negative. This could be indicative of a substitution effect between these types of operation. Finally, the residual in regression (4) has a significant MA(1) process which is consistent with a shared transitory component in the structural model but it becomes insignificant in the restricted models.

The last three regression results presented in Table 2 concern the second crisis period. In this case there is only an allotment variable to consider (since the settlement rate is fixed). An immediately obvious difference between these regression results and those for the Crisis I period concerns the decline in the goodness of fit measure to less than 5%. There is clearly a diminished ongoing relationship between the two funding venues for this period. There remains a significant end-of-maintenance period effect but the effect from previous LTROs is opposite in sign to what was found for the Crisis I period. More importantly, there is no relationship between auction allotment and average daily repo market activity until a second lag of average daily repo activity is included and this effect is positive rather than negative as would be expected if the venues are substitutes for each other.

We now consider the regression results for the supplementary regressions tabulated in Table 3. These regression results also cover the crisis period and the main question is whether the residuals from the relevant regressions in Table 2 make any contribution to explaining average daily repo market activity in the days after auctions (in the case of the Crisis I period we include residuals from both the settlement rate regression, $Resid : \dot{P}^{auc}_{t-1}$, and the allotment regression, $Resid : \dot{Q}^{auc}_{t-1}$). We also expect a reduction in the auto-correlation of the error term in the repo activity regression when the various control variables are included.

The first three regressions in Table 3 involve the use of control variables based on the change in the log of CDS spreads for sovereign bonds and for simple CDS indexes of the main banks within a number of periphery countries and for Germany. These CDS spreads become unreliable in the second crisis period and for this reason we compare results for both periods using repo market microstructure variables (spread and depth measures) as controls in regressions (4) to (9). In unrestricted regressions (and in restricted regressions where it remains significant) we also include the Euribor-OIS spread.

In the Crisis I period there is ample evidence for a link between repo market activity and auction behaviour. All of the Crisis I regressions have goodness of fit measures in excess of 40%. There are quite a number of the controls that are significant in both sets of models but coefficient signs are not easily interpreted, which probably reflects the fact that many of these are correlated with each other.[21] It is interesting that the control variables with most statistical significance from the two different groups are associated with almost the same set of countries (Germany, Italy and Portugal feature prominently).

We turn now to a discussion of the cross-effects from auction outcomes. Firstly, the residuals from the auction allotment equation always have a negative sign (even in the Crisis

[21] We conducted the analysis using the principal components of the controls and this produced similar results more parsimoniously (results are available from the authors on request).

II period). However, these coefficients are not statistically significant at conventionally acceptable levels. This therefore gives meta-support for the expected effect but otherwise very weak evidence of a benign substitution effect flowing from auctions to the post-auction repo market.

The price effect in all six of the Crisis I regressions is highly significant (i.e., significant at better than 99% level of confidence). However, the price effect is also positive. This indicates that the price effect from aggressive bidding in auctions outweighs any benign distributional effects associated with funding going disproportionally to the most needy banks.

The results for the second crisis period shows a complete lack of any relationship between interbank market activity and auction allotment. We regard the results for the second crisis period as indicative of a separation in the type of participants in the two funding venues. The repo market has high quality counterparties dealing with each other at repo rates below the fixed rate that is available from ECB auctions. In contrast, participants in auctions are most likely to be those that are unable to access the interbank market either because they have insufficient high quality collateral or because they are known to be be highly risky counter parties.

6 Conclusion

This paper examines the relationship between euro interbank borrowing and lending activity and the actions of the ECB in terms of liquidity providing operations and interest rate events. The analysis considers the pre-crisis period and then two different auction regimes within the crisis sample. In the pre-crisis sample a VAR-ECM approach is used to uncover the causal linkages between the two funding sources with allowances made for different types of seasonality. A structural model is proposed for the crisis period and this gives rise to a modified-VMA representation and a sequential empirical methodology that is capable of identifying how auctions matter for interbank activity when the interbank market is affected by changes in the quality of counterparties and by collateral and liquidity hoarding shocks.

The analysis of the pre-crisis period indicates that outcomes of official funding operations have direct effects on interbank repo market activity. The effects of outcomes of liquidity providing operations in the pre-crisis period are statistically significant but not very large. It seems likely that the amount of official funding provided (and its terms) did not act as a binding constraint on the use of short term funding for most of the pre-crisis period following the bursting of the dot-com bubble. There was a significant growth in repo market activity (that is likely to be, to some extent, related to a more connected and integrated network for the sharing of liquidity across the euro area banking sector). This meant that official funding became an increasingly smaller proportion of the volume of interbank activity (and therefore less of a significant constraint). Despite the continued broadening of funding opportunities, due to improved trading infrastructure, an event analysis of interest rate increases shows that monetary policy was somewhat effective in constraining the sharing of such funding in the period from November 2005 to mid-2007. The slack funding conditions in the 2003-2005 period may have produced the vulnerabilities that were subsequently revealed by the crisis (i.e., banks may have become overly reliant on seemingly dependable opportunities to roll-over cheap funding using plentiful collateral and this left them vulnerable when collateral quality declined and counterparty risk increased, and when there was hoarding of reserves and collateral).

The analysis of the crisis period shows that access to official funding can work in different ways to ameliorate the effects of the contraction of the sharing of liquidity in the repo market. Firstly, it is possible that aggressive bidding in auctions, by those banks with the fewest opportunities for interbank funding, may produce a better allocation of funding to where it is most needed (i.e., the aggressive bidders take a disproportionate amount of the funding on offer). This could also encourage banks with better interbank access to favour interbank funding due to the weighted average price rise, the price-effect, or simply because such under-bidding banks are more likely to be left without allocations if the marginal rate is allowed to rise. More directly, since there were some changes in the amount allotted in auctions even before full-allotment was introduced, this could have directly affected the amount of sharing of liquidity that was required in the interbank market. However, our analysis shows that the price effects from aggressive bidding led to increased post-auction activity and this implies that the price effect was greater than either the allocation effects or from the quantity effect due to increased overall allotment (although we find the correct sign on the quantity effect). The post-Lehman period (when fixed-rate full-allotment was introduced) seems to be consistent with an over-provision of liquidity and a reduced (insignificant) interaction between the two funding sources. We interpret this as evidence of a separation of the market into 'good' and 'bad' banks with the latter dependent on official funding and the former prepared to transact in the interbank market at a repo rate that is significantly below the fixed rate available in auctions.

Overall, the analysis of the pre-Lehman crisis period points to a trade-off between quantity and price effects that could be harnessed by policy makers when returning to more normal variable-rate operations. We have found that the price-effects from aggressive bidding in variable rate auctions drives some banks back to private sharing of funding and this could be viewed as a good development. However, this could also lead to too large a separation of the auction rate from the intended policy rate and this would be undesirable from the point of view of monetary policy transmission. Therefore, to avoid extreme weighted average settlement rates in auctions, allotment quantity could be varied (initially increased) to attenuate extreme aggressive bidding. Our analysis gives some indication that increased allotment quantity would subdue interbank market stresses during the transition. Over time, a schedule of progressively declining allotment quantities could be announced to allow banks to prepare for the planned adjustment. As the analysis above shows, the price and quantity effects from such auctions on repo market activity can be monitored and measured and therefore allotment quantity could be adjusted towards an optimal level as required.

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7 Figures

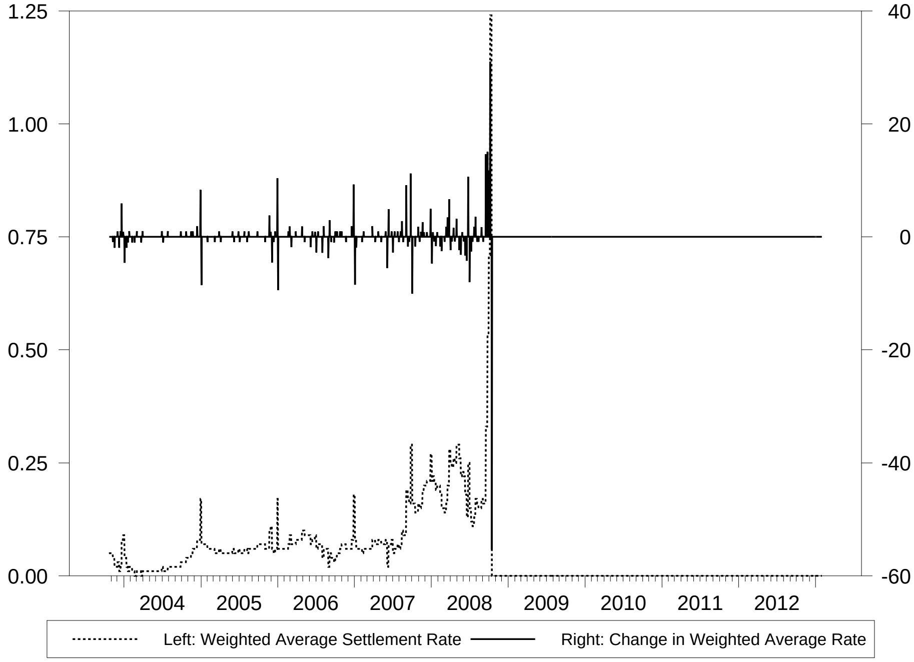

Figure 1: This figure shows the weighted average settlement rate as a deviation from the ECB target rate (on the chart baseline and measured against the scale on the left axis) and the change in the weighted average settlement rate relative to the ECB marginal lending rate (upper section of graph space and measured against the scale on the right axis).

Note: Amounts are in basis points (right axis) and percentages (left axis). When the fixed-rate full allotment auctions apply the auction rate equals the policy rate and both variables are zero.

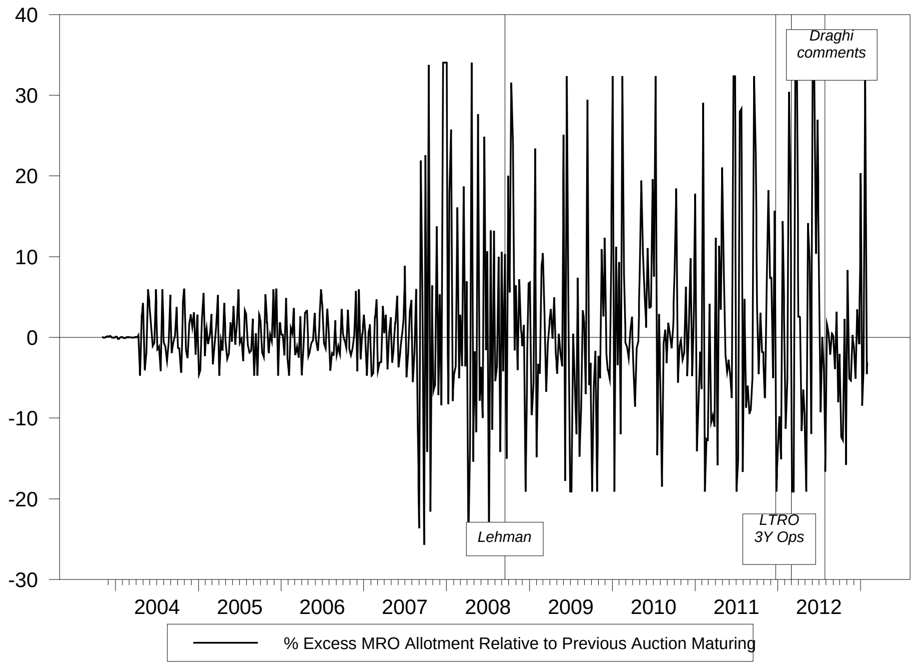

Figure 2: This figure shows the amount allotted in MRO auctions in excess of maturing amounts from the previous auction as % of maturing amounts.

Note: Amounts are percentage points.

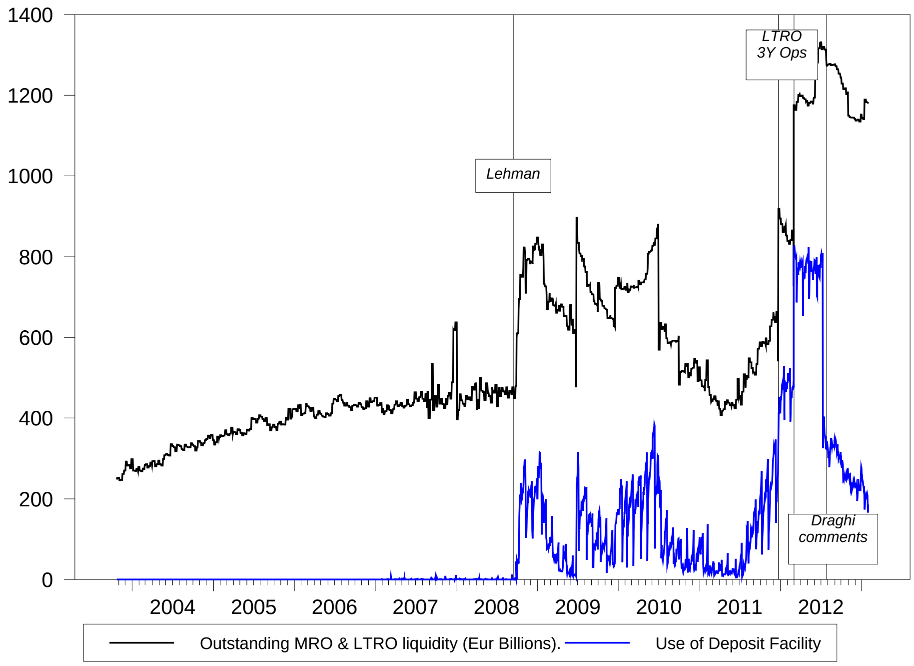

Figure 3: The liquidity provided through MRO and LTRO operations is shown along-side the amount of liquidity deposited in the ECB's Deposit Facility.

Note: Amounts are shown in billions of euro.

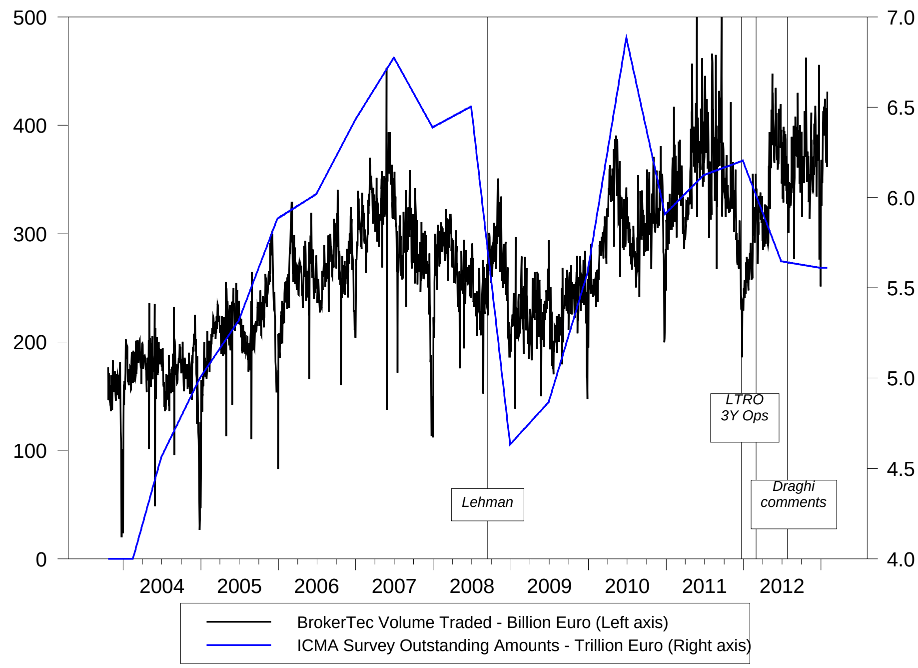

Figure 4:Repo volume ICMA Survey and BrokerTec ATS.

Note: The BrokerTec daily volume of trading in repos using sovereign collateral issued by ten euro area sovereigns is shown in billions of euro. Also shown is the six monthly survey of outstanding amounts of repo transactions (in trillions of euro) of roughly 70 of the largest banks in the European Union where there is linear interpolation between the observed amounts.

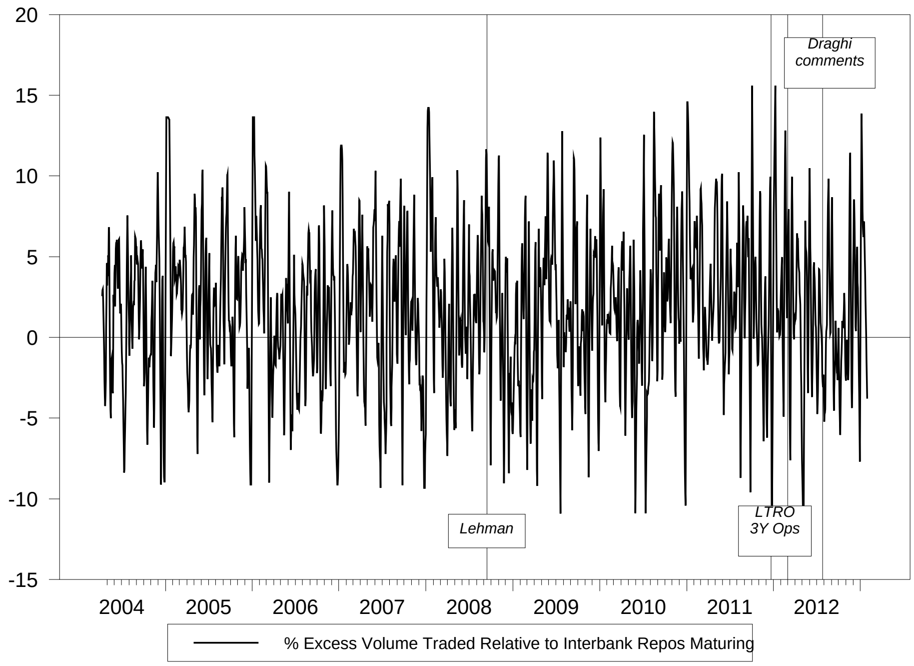

Figure 5: Traded volume on BrokerTec ATS in Excess of Maturing Amounts as % of Maturing Amounts.

Note: To help in visualizing the main movement in this series we display the 5 day moving average of the raw series. Also, observations exceeding the 5% tails of the data are capped at the tail percentile levels.

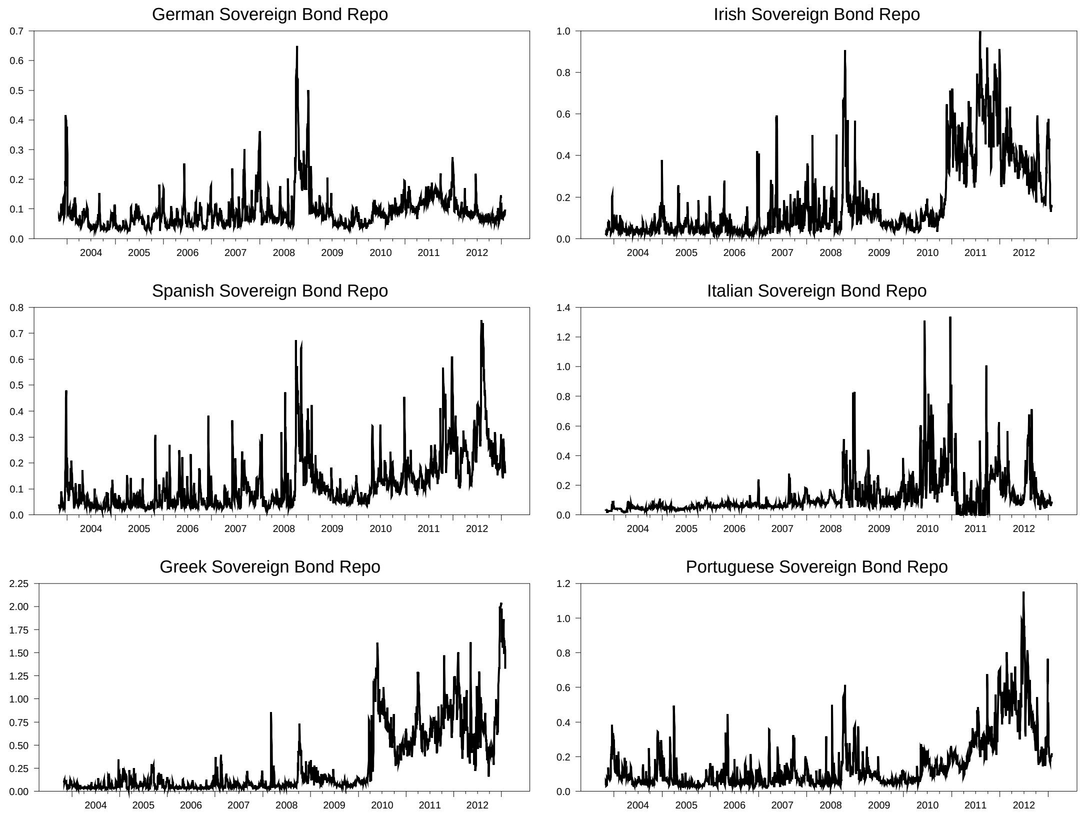

Figure 6: The log of the time weighted average bid ask spread in basis points for repos based on selected sovereign collateral.

Note: The spread within each market is first time-weighted (where only two-sided quoting is timed) and then averaged across term-specific contracts.

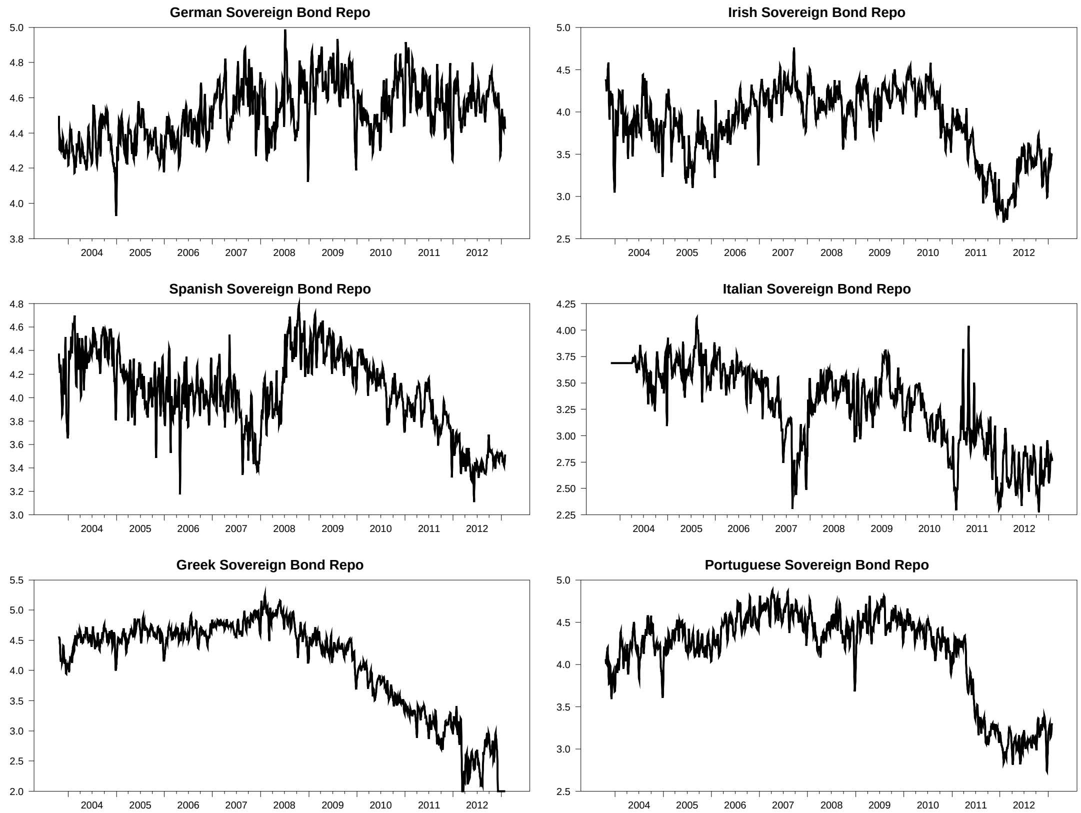

Figure 7: The log of the quantity on the orderbook (million euro) for repos based on selected sovereign collateral.

Note: The full book is included in this calculation. All variables have been smoothed using a 5 day centered moving average. The raw variables are used in the regression analysis.

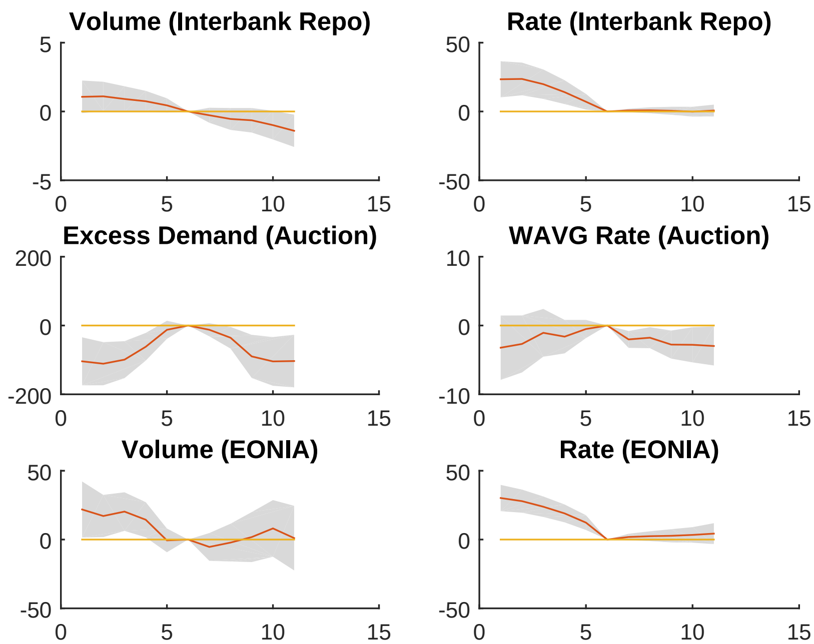

Figure 8: Cumulative sum of coefficients on pre- and post-event dummies for 8 interest rate changes prior to the market turmoil of 2007.

Note: We included 10 dummy variables in the VAR-ECMs tabulated in Tables 1(a), 1(b) and 1(c). Each dummy is designed to pick out one of the five weeks before and after the 8 interest rate rises that occurred between November 2005 and June 2007. The pre-event coefficients are accumulated starting with the nearest one to the event and a standard error is calculated for each of the sums until the 5th week in advance of the event is reached. The post-event coefficients are accumulated (summed) starting at the event and proceeding until the 5th week after the event. The cumulative sums of coefficients and their 95%standard error bounds are presented. Volumes and rates in the repo and EONIA market decline significantly before rate rises (controlling for all other effects). Interest rates in both markets stabilise afterwards but volume in the repo market continues to decline. In MRO auctions there is a rise in the amount of unallocated bids and this subsides afterwards. The auction rate rises in the run-up to the rate rise and then falls significantly.

8 Tables

	Dependent: $\dot{Q}_t^{repo}$				Dependent: P_t^{repo}			
	Unrestricted		Restricted		Unrestricted		Restricted	
	Lag 1	Lag 5	Lag 1	Lag 5	Lag 1	Lag 5	Lag 1	Lag 5
$\dot{Q}^{repo}$	$-0.146^{\bar{*}}$	0.01	$-0.143^{\bar{*}}$		0.058	-0.28		
	(0.067)	(0.041)	(0.063)		(0.311)	(0.287)		
P^{repo}	-1.697	1.838	-1.549		0.076	-0.032		
	(1.275)	(1.572)	(1.17)		(0.058)	(0.064)		
D^{auc}	$0.002^{\bar{*}}$	-0.001	$0.002^{\bar{*}}$		-0.002	0.007^{*}		0.006
	(0.001)	(0.001)	(0.001)		(0.005)	(0.004)		(0.003)
P^{auc}	-0.01	0.011			0.061	0.116		$0.205^{\bar{\bar{*}}}$
	(0.02)	(0.015)			(0.091)	(0.081)		(0.076)
$\dot{Q}^{eonia}$	-0.002	-0.002			-0.021^{*}	-0.013	-0.024^{*}	
	(0.003)	(0.003)			(0.012)	(0.014)	(0.013)	
P^{eonia}	0.028	-0.003	0.024^{*}		-0.012	0.063		
	(0.018)	(0.018)	(0.014)		(0.054)	(0.067)		
$\dot{Q}^{eurex}$	0.029	-0.631		$-0.466^{\bar{\bar{*}}}$	-0.455	2.984		
	(0.298)	(0.394)		(0.211)	(1.456)	(2.36)		
P^{eurex}	-0.013	-0.011			0.072	$-0.19^{\bar{*}}$		-0.104
	(0.019)	(0.017)			(0.095)	(0.081)		(0.071)
$\dot{M}^{repo}$	-0.076	-0.044	$-0.102^{\bar{*}}$		0.23	0.094		
	(0.051)	(0.039)	(0.049)		(0.375)	(0.148)		
ECM^{repo}	$-4.905^{\bar{\bar{*}}}$		$-4.975^{\bar{\bar{*}}}$		$-10.47^{\bar{*}}$		$-12.587^{\bar{\bar{*}}}$	
	(0.796)		(0.757)		(4.514)		(3.605)	
E^{swap}	0.444^{*}		0.394^{*}		$-36.428^{\bar{\bar{*}}}$		$-35.272^{\bar{\bar{*}}}$	
	(0.254)		(0.237)		(6.425)		(6.643)	
$V1X_t$	$0.061^{\bar{*}}$		$0.065^{\bar{\bar{*}}}$		-0.09			
	(0.024)		(0.023)		(0.139)			
VIX_{t-1}	-0.042^{*}		$-0.045^{\bar{*}}$		-0.141			
	(0.023)		(0.022)		(0.15)			

Table 1.a: Regression results for the **pre-crisis** period for the **repo-market equations** of the VAR model outlined in Section 3.1 are presented ($\bar{R}^2$ was 0.54, 0.55, 0.61 and 0.62 for the 4 regressions respectively). The number of observations is 233 which includes MRO operations between March 15th 2004 and June 24th 2007. Coefficient estimates are displayed with Heteroscedasticity-Consistent (Eicker-White) Standard Errors in parentheses ($\bar{\bar{*}}$, $\bar{*}$ and $*$ respectively indicate sizes of the underlying p-values as follows; $p < 0.01$, $0.01 < p < 0.05$ or $0.05 < p < 0.10$). The dependent variable $\dot{Q}_t^{repo}$ is the change in volume traded on the BroketTec platform while P_t^{repo} is deviation between the weighted average auction rate and the ECB's deposit rate. Dummy coefficient estimates omitted.

	Dependent: D_t^{auc}						Dependent: P_t^{auc}					
	Unrestricted			Restricted			Unrestricted			Restricted		
	Lag 0	Lag 1	Lag 5	Lag 0	Lag 1	Lag 5	Lag 0	Lag 1	Lag 5	Lag 0	Lag 1	Lag 5
$\dot{Q}^{repo}$	-7.011^{*}	-4.814	-2.36				-0.271	$0.332^{\bar{*}}$	-0.155^{*}		$0.305^{\bar{*}}$	
	(3.788)	(4.19)	(2.814)				(0.212)	(0.146)	(0.091)		(0.13)	
P^{repo}	$1.443^{\bar{*}}$	-0.581	0.548	$2.006^{\bar{\bar{*}}}$			$0.087^{\bar{*}}$	0.006	0.031	$0.086^{\bar{\bar{*}}}$		
	(0.643)	(0.6)	(0.665)	(0.712)			(0.035)	(0.033)	(0.027)	(0.024)		
D^{auc}		$0.39^{\bar{\bar{*}}}$	0.058		$0.402^{\bar{\bar{*}}}$			-0.001	-0.003			
		(0.096)	(0.073)		(0.074)			(0.002)	(0.003)			
P^{auc}		$-2.704^{\bar{*}}$	$-3.408^{\bar{\bar{*}}}$		-1.456	$-3.049^{\bar{\bar{*}}}$		$0.673^{\bar{\bar{*}}}$	-0.018		$0.663^{\bar{\bar{*}}}$	
		(1.205)	(0.828)		(1.146)	(0.922)		(0.082)	(0.063)		(0.058)	
$\dot{Q}^{eonia}$	-0.035	0.002	-0.02				$0.017^{\bar{*}}$	0.002	-0.009	$0.017^{\bar{*}}$		
	(0.191)	(0.182)	(0.154)				(0.008)	(0.007)	(0.006)	(0.007)		
P^{eonia}	1.032	1.408^{*}	0.586				0.027	0.036	-0.012			
	(1.054)	(0.788)	(0.765)				(0.039)	(0.037)	(0.024)			
$\dot{Q}^{eurex}$	0.004	-34.62	-1.467					$-3.384^{\bar{\bar{*}}}$	$3.787^{\bar{*}}$		$-3.033^{\bar{\bar{*}}}$	$-4.019^{\bar{\bar{*}}}$
	(0.003)	(30.288)	(36.683)					(0.877)	(1.574)		(0.883)	(1.498)
P^{eurex}	-1.016	$-1.756^{\bar{*}}$	-0.337				0.014	-0.107^{*}	0.035			
	(0.879)	(0.876)	(0.969)				(0.052)	(0.06)	(0.041)			
$\dot{M}^{repo}$	-4.638	-4.293	0.026				-0.036	$0.253^{\bar{*}}$	-0.023		$0.235^{\bar{\bar{*}}}$	
	(4.588)	(3.871)	(3.076)				(0.165)	(0.129)	(0.082)		(0.084)	
ECM^{repo}		-33.294						$-6.387^{\bar{\bar{*}}}$			$-5.516^{\bar{\bar{*}}}$	
		(45.296)						(2.428)			(1.698)	
E^{swap}	$76.782^{\bar{*}}$	11.03		41.384^{*}			2.252	$4.295^{\bar{\bar{*}}}$			$3.421^{\bar{\bar{*}}}$	
	(32.456)	(33.612)		(23.793)			(1.408)	(1.627)			(1.228)	
$V1X$	-1.944	1.069		$-2.425^{\bar{\bar{*}}}$			-0.01	0.041				
	(1.57)	(1.717)		(0.814)			(0.067)	(0.064)				

Table 1.b: Regression results for the **pre-crisis** period for the **auction equations** of the VAR model outlined in Section 3.1 are presented ($\bar{R}^2$ was 0.43, 0.43, 0.93 and 0.93 for the 4 regressions respectively). The number of observations is 213 which includes MRO operations between March 15th 2004 and June 24th 2007. Coefficient estimates are displayed with Heteroscedasticity-Consistent (Eicker-White) Standard Errors in parentheses ($\bar{\bar{*}}$, $\bar{*}$ and $*$ respectively indicate sizes of the underlying p-values as follows; $p < 0.01$, $0.01 < p < 0.05$ or $0.05 < p < 0.10$). The dependent variable D_t^{auc} is excess demand while P_t^{auc} the percentage deviation between the weighted average auction rate and the ECB's target rate. Dummy coefficient estimates omitted.

	Dependent: $\dot{Q}_t^{eonia}$				Dependent: P_t^{eonia}			
	Unrestricted		Restricted		Unrestricted		Restricted	
	Lag 1	Lag 5	Lag 1	Lag 5	Lag 1	Lag 5	Lag 1	Lag 5
$\dot{Q}^{repo}$	0.107	0.422			0.543	-0.053		
	(1.284)	(0.81)			(0.393)	(0.266)		
P^{repo}	0.205	$0.426^{\bar{*}}$		0.266^{*}	0.161^{*}	-0.09	$0.203^{\bar{\bar{*}}}$	
	(0.19)	(0.187)		(0.153)	(0.085)	(0.071)	(0.063)	
D^{auc}	$0.034^{\bar{*}}$	-0.023	0.016		-0.002	0		
	(0.017)	(0.017)	(0.012)		(0.006)	(0.005)		
P^{auc}	0.163	-0.267			$0.293^{\bar{*}}$	$-0.196^{\bar{*}}$		-0.134
	(0.39)	(0.292)			(0.134)	(0.098)		(0.092)
$\dot{Q}^{eonia}$	$-0.348^{\bar{\bar{*}}}$	$0.151^{\bar{\bar{*}}}$	$-0.356^{\bar{\bar{*}}}$	$0.143^{\bar{\bar{*}}}$	0.175	0.007		
	(0.048)	(0.05)	(0.043)	(0.047)	(1.479)	(1.589)		
P^{eonia}	-0.222	$-0.494^{\bar{*}}$		-0.291^{*}	0.057	0.126^{*}		0.063
	(0.193)	(0.2)		(0.149)	(0.076)	(0.073)		(0.051)
$\dot{Q}^{eurex}$	-1.29	-2.861			-1.872	2.079		
	(6.973)	(7.018)			(2.254)	(2.742)		
P^{eurex}	-0.083	0.179			-0.07	$-0.356^{\bar{\bar{*}}}$		$-0.277^{\bar{\bar{*}}}$
	(0.242)	(0.189)			(0.119)	(0.096)		(0.093)
$\dot{M}^{repo}$	1.753	-0.403	0.991		-0.301	-0.135		
	(1.129)	(0.719)	(0.689)		(0.293)	(0.178)		
ECM^{repo}	0.508				-8.483^{*}			
	(13.378)				(4.507)			
E^{swap}	-2.481				$-36.101^{\bar{\bar{*}}}$		$-35.652^{\bar{\bar{*}}}$	
	(7.163)				(3.049)		(2.977)	
$V1X_t$	-0.581				-0.269^{*}		$-0.174^{\bar{*}}$	
	(0.442)				(0.147)		(0.074)	
$V1X_{t-1}$	0.681				0.198			
	(0.439)				(0.14)			

Table 1.c: Regression results for the **pre-crisis** period for the **eonia-market equations** of the VAR model outlined in Section 3.1 are presented ($\bar{R}^2$ was 0.46, 0.49, 0.60 and 0.61 for the 4 regressions respectively). The number of observations is 213 which includes MRO operations between March 15th 2004 and June 24th 2007. Coefficient estimates are displayed with Heteroscedasticity-Consistent (Eicker-White) Standard Errors in parentheses ($\bar{\bar{*}}$, $\bar{*}$ and $*$ respectively indicate sizes of the underlying p-values as follows; $p < 0.01$, $0.01 < p < 0.05$ or $0.05 < p < 0.10$). The dependent variable $\dot{Q}_t^{eonia}$ is the change in volume traded by surveyed banks in the EONIA market while P_t^{eonia} is deviation between daily average eonia rate between MRO auctions and the ECB's target rate. Dummy coefficient estimates omitted.

	Dependent: $\dot{P}^{auc}$			Dependent: $\dot{Q}^{auc}$					
Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Period	Crisis I	Crisis I	Crisis I	Crisis I	Crisis I	Crisis I	Crisis II	Crisis II	Crisis II
$\bar{R}^2$	0.106	0.13	0.117	0.471	0.467	0.467	0.031	0.045	0.047
D-W Statistic	1.847	1.853	1.853	1.963	1.973	1.981	1.988	1.988	2.061
F-Test Exclusions		0.394	0.794		1.235	2.467		0.081	
Significance Level		[0.812]	[0.557]		[0.302]	[0.051]		[0.995]	
Constant	1.889	$1.557^{\bar{*}}$	$1.490^{\bar{*}}$	-1.501			-4.185	$-3.517^{\bar{*}}$	$-3.549^{\bar{*}}$
	(1.546)	(0.685)	(0.683)	(2.831)			(2.787)	(1.741)	(1.755)
Year End	$-17.806^{\bar{\bar{*}}}$	$-16.768^{\bar{\bar{*}}}$	$-14.770^{\bar{\bar{*}}}$	$63.153^{\bar{\bar{*}}}$	$60.091^{\bar{\bar{*}}}$	$58.168^{\bar{\bar{*}}}$	0.594		
	(5.432)	(4.944)	(4.815)	(9.941)	(9.429)	(9.207)	(6.423)		
Year Start	2.337			-11.867			2.457		
	(5.074)			(9.273)			(6.628)		
$LAST_t$	0.28			$22.181^{\bar{\bar{*}}}$	$20.475^{\bar{\bar{*}}}$	$20.613^{\bar{\bar{*}}}$	$12.213^{\bar{\bar{*}}}$	$11.638^{\bar{\bar{*}}}$	$11.719^{\bar{\bar{*}}}$
	(2.546)			(4.783)	(3.679)	(3.678)	(4.294)	(3.748)	(3.721)
$LTRO_t$	0.527			4.297			0.564		
	(2.19)			(4.135)			(3.278)		
$LTRO_{t-1}$	-1.892			-5.834	$-6.942^{\bar{*}}$	$-6.796^{\bar{*}}$	5.467^{*}	5.08^{*}	5.089^{*}
	(2.104)			(3.923)	(2.777)	(2.774)	(3.279)	(2.787)	(2.743)
$\dot{Q}_t^{repo}$	$-0.294^{\bar{*}}$	$-0.256^{\bar{*}}$	$-0.273^{\bar{*}}$	-0.192	-0.26	-0.232	0.058		
	(0.125)	(0.12)	(0.12)	(0.238)	(0.229)	(0.228)	(0.131)		
$\dot{Q}_{t-1}^{repo}$	-0.138	-0.165		0.1	0.203		0.013		
	(0.119)	(0.106)		(0.224)	(0.205)		(0.128)		
$\dot{Q}_{t-2}^{repo}$							$0.337^{\bar{\bar{*}}}$	$0.328^{\bar{\bar{*}}}$	$0.328^{\bar{\bar{*}}}$
							(0.128)	(0.125)	(0.125)
ρ_{auc}	-0.135	-0.169	-0.180	-0.206^{*}	-0.174	-0.162	-0.029	-0.031	
	(0.13)	(0.124)	(0.125)	(0.107)	(0.105)	(0.104)	(0.056)	(0.056)	

Table 2: The tabulated results are for regressions explaining the auction outcomes. The number of observations is 98 and 329 for Crisis I and Crisis II respectively. The Crisis I period is 19th June 2007 to 7th September 2008 and the Crisis II period is from 16th Dec 2008 to 30th Jan 2013. For the case of the weighted average settlement rate, $\dot{P}^{auc}$, we selected regression (3) as the preferred specification. For the case of allotment quantity, $\dot{Q}^{auc}$, we selected regression (5) as the preferred specification for Crisis I and regression (9) for Crisis II. The residuals from the preferred specifications are used in the repo volume regressions considered in the following table. Coefficient estimates are displayed with standard errors in parentheses ($\bar{\bar{*}}$, $\bar{*}$ and $*$ respectively indicate sizes of the underlying p-values as follows; $p < 0.01$, $0.01 < p < 0.05$ or $0.05 < p < 0.10$). The $\bar{R}^2$ and Durbin Watson statistic are shown in the top panel. The F-statistics and associated significance levels are also provided for the joint test of exclusion restrictions implied by regressions 2 and 3 relative to regression 1, regressions 5 and 6 relative to regression 4, and regression 8 relative to regression 7.

					Dependent: $\dot{Q}^{Repo}$					
Regression	(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)	(9)
Period	Crisis I	Crisis I	Crisis I		Crisis I	Crisis I	Crisis I	Crisis II	Crisis II	Crisis II
$\bar{R}^2$	0.437	0.473	0.470		0.493	0.513	0.502	0.053	0.073	0.067
D-W Statistic	2.051	2.042	2.029		2.028	2.023	2.172	1.998	1.999	1.900
F-Test Exclusions		0.450	0.519			0.674	0.658		0.324	0.327
Significance Level		[0.916]	[0.885]			[0.745]	[0.773]		[0.974]	[0.979]
$Resid: \dot{P}^{auc}_{t-1}$	$0.363^{\bar{\bar{*}}}$	$0.362^{\bar{\bar{*}}}$	$0.372^{\bar{\bar{*}}}$		$0.431^{\bar{\bar{*}}}$	$0.408^{\bar{\bar{*}}}$	$0.4^{\bar{\bar{*}}}$			
	(0.095)	(0.089)	(0.089)		(0.089)	(0.085)	(0.085)			
$Resid: \dot{Q}^{auc}_{t-1}$	-0.026	-0.025			-0.037	-0.031		-0.013	-0.014	
	(0.044)	(0.041)			(0.044)	(0.041)		(0.024)	(0.023)	
$\triangle CDS^{Bank}_{DE}$	$-25.181^{\bar{*}}$	$-25.494^{\bar{*}}$	$-28.209^{\bar{*}}$	$\triangle Spread_{DE}$	2.691^{*}	2.465^{*}	2.633^{*}	-2.339		
	(12.587)	(11.489)	(11.563)		(1.578)	(1.382)	(1.344)	(2.712)		
$\triangle CDS^{Bank}_{ES}$	15.479	12.877		$\triangle Spread_{ES}$	-1.199			0.466		
	(10.554)	(9.795)			(1.264)			(1.865)		
$\triangle CDS^{Bank}_{GR}$				$\triangle Spread_{GR}$	-1.213			$3.025^{\bar{*}}$	$3.158^{\bar{*}}$	$3.307^{\bar{*}}$
					(1.425)			(1.535)	(1.471)	(1.493)
$\triangle CDS^{Bank}_{IE}$	9.864	11.418^{*}	11.281^{*}	$\triangle Spread_{IE}$	-0.162			-1.513		
	(6.145)	(5.831)	(5.902)		(0.953)			(2.018)		
$\triangle CDS^{Bank}_{IT}$	$34.755^{\bar{*}}$	$31.963^{\bar{*}}$	$29.482^{\bar{*}}$	$\triangle Spread_{IT}$	-4.833^{*}	$-6.511^{\bar{*}}$	$-6.889^{\bar{\bar{*}}}$	$-2.192^{\bar{*}}$	$-2.138^{\bar{*}}$	$-1.888^{\bar{*}}$
	(14.353)	(12.838)	(11.526)		(2.823)	(2.486)	(2.46)	(0.926)	(0.867)	(0.873)
$\triangle CDS^{Bank}_{PT}$	-25.625^{*}	-20.566^{*}		$\triangle Spread_{PT}$	$-2.676^{\bar{*}}$	$-2.408^{\bar{*}}$	$-2.606^{\bar{*}}$	2.335		
	(13.121)	(12.166)			(1.219)	(1.129)	(1.106)	(2.175)		
$\triangle CDS^{Sov}_{DE}$	-2.485			$\triangle Q^{Ask}_{DE}$	$-13.695^{\bar{\bar{*}}}$	$-12.817^{\bar{\bar{*}}}$	$-10.707^{\bar{\bar{*}}}$	$-10.203^{\bar{*}}$	$-9.577^{\bar{*}}$	-7.968
	(4.517)				(4.5)	(3.545)	(3.493)	(5.025)	(4.831)	(4.867)
$\triangle CDS^{Sov}_{ES}$	1.901			$\triangle Q^{Ask}_{ES}$	3.355			4.369		
	(8.866)				(3.433)			(5.448)		
$\triangle CDS^{Sov}_{GR}$	10.285			$\triangle Q^{Ask}_{GR}$	-7.784			-1.183		
	(14.409)				(5.241)			(3.082)		
$\triangle CDS^{Sov}_{IE}$	-1.772			$\triangle Q^{Ask}_{IE}$	-4.4			-1.375		
	(5.227)				(4.009)			(3.852)		
$\triangle CDS^{Sov}_{IT}$	$46.376^{\bar{*}}$	$53.34^{\bar{\bar{*}}}$	$58.913^{\bar{\bar{*}}}$	$\triangle Q^{Ask}_{IT}$	$-8.942^{\bar{*}}$	$-8.963^{\bar{*}}$	$-8.367^{\bar{*}}$	0.565		
	(22.679)	(19.576)	(19.313)		(3.934)	(3.653)	(3.487)	(2.659)		
$\triangle CDS^{Sov}_{PT}$	-39.834^{*}	$-39.659^{\bar{*}}$	$-45.679^{\bar{*}}$	$\triangle Q^{Ask}_{PT}$	-1.682			$11.047^{\bar{*}}$		$10.596^{\bar{*}}$
	(21.508)	(18.949)	(18.561)		(5.056)			(5.297)		(4.835)
$\triangle EURIB$ -OIS	-1.582			$\triangle EURIB$ -OIS	-1.242			1.441		1.456^{*}
	(1.746)				(1.877)			(0.893)		(0.861)
ρ_{repo}	-0.107	-0.098			-0.176	-0.125		0.069		
	(0.122)	(0.115)			(0.121)	(0.107)		(0.059)		

Table 3: Results for pre- and post-Lehman periods are shown (the regression is described in Section 3.2). There 98 and 329 observations in the pre- and post-Lehman periods respectively. The pre-Lehman period runs from 19th June 2007 to 7th September 2008 and the post-Lehman period runs from 16th Dec 2008 to 30th Jan 2013. Standard errors are in parentheses ($\bar{\bar{*}}$, $\bar{*}$ and $*$ respectively indicate sizes of p-values as follows; $p < 0.01$, $0.01 < p < 0.05$ or $0.05 < p < 0.10$). Coefficients of additive dummy variables are not shown. $\bar{R}^2$ and Durbin Watson statistics are shown in the top panel. The F-statistics and their significance are provided for exclusion restrictions implied by regressions 2 and 3 relative to 1, regressions 5 and 6 relative to 4, and regressions 8 and 9 relative to 7.