

SUPPLEMENT TO “THE 2007 SUBPRIME MARKET CRISIS
THROUGH THE LENS OF EUROPEAN CENTRAL BANK AUCTIONS
FOR SHORT-TERM FUNDS”

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APPENDIX B

B.1. An Iterative Algorithm to Classify Bidders When Their Group Membership Is not Observed

WE ADOPT AN ITERATIVE PROCEDURE and estimate an asymmetric model with two groups of banks as follows. In the first step, we start the algorithm by arbitrarily allocating bank identities across two groups: banks that suffered from the crisis (group indexed with b for “bad” banks) and those that did not (group indexed with h for “healthy” banks).¹ The resampling method is modified to allow for two groups of bidders that are symmetric within a group, but not necessarily across the groups. This is achieved by drawing with replacement from observed bids from each group separately. We thus obtain estimates of the marginal values of each bidder in every auction. In the second step, we use these estimated values to find a subset of bidders who experienced a stochastic increase in their estimated values for liquidity in the post-turmoil period. We assume that experiencing financial distress in our model translates into a shift in the distribution of marginal values in the sense of first-order stochastic dominance. There are many alternatives to check for this shift, and the test we use is based on comparing means of the distributions before and after turmoil for each bidder. This test is operationalized by regressing the quantity-weighted average of the marginal value estimates (normalized by EONIA to take out the level effect of interest rates²) on the turmoil dummy for each bidder separately. If the estimated coefficient on the turmoil dummy is significant at the 5% level, that is, if the mean marginal value increased, we classify this bidder as one who experienced financial distress in the post-turmoil period. In the third step of our algorithm, we re-estimate the model using the newly obtained two groups of bidders.³ In the fourth step, we again estimate the subset of bidders that experienced an increase in their values by using the estimates from the

¹In practice, we started both with allocating all banks into the Healthy Group and with a random allocation, both of which led to statistically indistinguishable estimates.

²See Piazzesi (2009) for a thorough discussion of the recent literature on the structure of interest rates.

³Bidders are treated asymmetrically in all auctions. That is, we fix the two groups even before turmoil. Had the bidders been actually symmetric before turmoil, our approach would result only in loss of efficiency, but the estimates of the distribution of the market clearing price would still be consistent.

asymmetric model. If this subset coincides with the two groups used in step 3, then we stop; otherwise, we repeat step 3.⁴ In practice, we stop the algorithm when weakly less than 5 bidder identities switch groups. We are able to classify 482 bidder identities out of the 733 in our data. The remaining bidder identities do not submit bids both before and after the turmoil.

As we indicate in Section 5.3.1, that the initial assignment of banks into groups does not seem to matter in our application is due to the fact that we have a large number of banks in each group. This, in turn, results in virtually the same estimates of marginal values (whether a bidder was assigned to b or h) and hence essentially unique allocation of bidders into the two groups. We conjecture that the impact of the asymmetry on the estimates of marginal values, and thus on the identification of the latent types, would likely be much more profound with a small number of bidders in each group.

B.2. Institutional Background

B.2.1. Objectives and Tools of the ECB

The operational framework for monetary policy implementation by the ECB has three main objectives: signaling of the monetary policy stance, steering of very short-term interest rates, and provision of refinancing to the banking system in an efficient way and under all circumstances. The ECB has three main tools to implement its objectives: minimum reserve requirements with averaging provision, standing facilities, and open market operations. The main focus of this paper is on open market operations, but below we briefly describe each of the three components because all are quite relevant for banks' behavior in the open market operations.

Reserve requirements have two main functions. They contribute to stabilize money market interest rates and enlarge the structural liquidity shortage of the banking system. Euro area banks have to keep minimum reserves (current accounts with national central banks⁵). They are computed on a lagged accounting basis by applying a reserve ratio (currently at 2%) to the reserve base. The reserve base includes short-term liabilities of banks (deposits and debt securities with maturity below or equal to two years). Reserves must be kept on average over a maintenance period (averaging mechanism) which has

⁴While we do not have a formal proof of whether this method converges, if it does, it is easy to see that the resulting estimates are consistent estimates of the primitives of the asymmetric model. In the actual application, it turns out that, after very few iterations, the two groups of bidders are very stable—both in terms of size and in terms of identities of bidders contained in each. The asymmetry, therefore, seems not to play as important a role in the estimation stage, which is probably due to the large number of participants. We experimented with a random initial assignment of bidders into the two groups; after very few iterations, we obtained virtually the same bidder groups as those arrived at when starting with the symmetric model.

⁵National Central Banks.

approximately one-month duration. Required reserves are remunerated—at a rate linked to the marginal rate of the Main Refinancing Operations (MROs) described below. Current account holdings beyond the minimum requirement are not remunerated (excess reserves).

There are two types of *standing facilities*, one providing liquidity (against collateral), which is a marginal lending facility, and another, absorbing liquidity, which is a deposit facility. Both are overnight facilities taken at the discretion of the banks, and, in general, there are no limits set by the ECB to their recourse by banks. Standing facilities have penalty rates: marginal lending +100 basis points above the Minimum Bid Rate (henceforth MBR, which is a policy rate; see below for more details) and deposit facility –100 basis points below the MBR.⁶ These two rates set a corridor for the interbank market overnight interest rate.

There are three main types of *open market operations*. The Main Refinancing Operations (MROs) are the main focus of our analysis. The Longer Term Refinancing Operations (LTROs) are liquidity-providing reverse transactions, with three-month maturity, conducted once a month, every month. The main function of the LTROs is to provide additional longer-term liquidity to the market. They are not intended to signal the (future) stance of monetary policy. Fine Tuning Operations (FTOs) provide or absorb liquidity. They have neither fixed frequency nor maturity. Provision of liquidity is made via reverse transactions or foreign exchange swaps, and absorption of liquidity is normally achieved via collection of fixed term deposits or foreign exchange swaps. The main function of the FTOs is to smooth the effects on interest rates caused by unexpected liquidity fluctuations in the market. Since 2005, the ECB conducts (almost) systematically an FTO on the last day of each reserve maintenance period.

B.2.2. *More Details on the Main Refinancing Operations*

MROs are executed weekly according to an indicative calendar published by the Eurosystem. Normally, the announcement of the operation is on Monday,⁷ the execution on Tuesday,⁸ and settlement on Wednesday. On the announcement day (Monday), the ECB publishes an estimate of the average autonomous factors⁹ from the announcement day until the maturity of the operation (9 days ahead forecast) as well as the benchmark allotment. On the execution day (Tuesday), the ECB publishes a revised estimate of the average autonomous factors and benchmark amount.

⁶The interest rate corridor was narrowed to ± 50 basis points as of October 9, 2008.

⁷Info in Reuters page ECB16.

⁸Info in Reuters page ECB17.

⁹Defined as Autonomous Factors (AF) = Net Foreign Assets (NFA) + Net Assets Denominated in Euro (NDA) – Banknotes (BN) – Government deposits (GOV) – Other (O).

As we mentioned earlier, a bid may consist of up to ten interest rates and associated quantities a bank is willing to transact with the ECB. The interest rate bid must be expressed as multiples of a basis point, that is, of 0.01 percentage points. The minimum bid amount is EUR 1,000,000. Bids exceeding this amount must be expressed as multiples of EUR 100,000. The ECB may impose a maximum bid limit in order to prevent disproportionately large bids.

In the allotment, bids are listed in descending order of offered interest rates. Bids with the highest interest rate levels are satisfied first, and subsequently, bids with successively lower interest rates are accepted until the total liquidity to be allotted is exhausted. If, at the lowest interest rate level accepted (i.e., the marginal interest rate), the aggregate amount bid exceeds the remaining amount to be allotted, the remaining amount is allocated pro rata among the bids according to the ratio of the remaining amount to be allotted to the total amount bid at the marginal interest rate (a.k.a. rationing rule pro rata on-the-margin). The amount allotted to each bank is rounded to the nearest euro.

The ECB may apply either single rate (uniform price) or multiple rate (discriminatory) auction procedures. So far, only the latter has been used, and thus our data include only discriminatory auctions. In a discriminatory auction, the allotment interest rate is equal to the interest rate offered by each individual bid. Since October 15, 2008, the weekly main refinancing operations have been carried out with a fixed-rate tender procedure with full allotment.

B.2.3. *Collateral (Eligible Assets)*

All Eurosystem liquidity-providing operations (including marginal lending and intraday credit) are based on underlying assets that must fulfill certain criteria in order to be eligible. A European credit assessment framework (ECAAF) has been set up to evaluate the eligible collateral. The collateral accepted by the Eurosystem is very broad. Two types of assets are included in the list: marketable and nonmarketable. The ECB publishes daily a list of eligible marketable assets on its website.¹⁰ Marketable assets must be debt instruments meeting high credit standards which are assessed by the ECAF rules. The issuers can be central banks, public sector, private sector, and international institutions; the place of issue must be EEA,¹¹ the place of establishment of the issuer must be the EEA and non-EEA G10 countries, the currency must be EUR.¹² Both regulated and nonregulated markets are considered; the latter must be, however, accepted by the ECB. Nonmarketable assets are credit claims and Retail Mortgage Backed Debt Instruments (RMBD). For credit claims, the debtor/guarantor must meet high credit standards which are assessed by the ECAF rules. The debtor/guarantor can be public sector, non-financial corporations, and international institutions; the place of establishment

¹⁰Eligible assets are listed at: https://mfi-assets.ecb.int/dla_EA.htm.

¹¹European Economic Area.

¹²Since November 14, 2008, the list of eligible marketable debt instruments was enlarged to include instruments denominated in U.S. dollar, yen, and sterling, issued by EEA issuers.

of the debtor/guarantor must be the euro area, and the currency must be EUR. Minimum size rules apply. For RMBD, the asset must meet high credit standards which are assessed by the ECAF rules. The issuers can be credit institutions; the place of establishment of the issuer must be the euro area, and the currency must be EUR. A bank may not submit as collateral any asset issued or guaranteed by itself or by any other entity with which it has close links.

In the assessment of credit standard of eligible assets, the Eurosystem takes into account the following sources: external credit assessment institutions (ECAIs), national central banks' in-house credit assessment systems (ICAS exist in Deutsche Bundesbank, Banco de España, Banque de France, and Oesterreichische Nationalbank), counterparties' internal ratings-based systems (IRB), or third-party providers' rating tools. The Eurosystem's credit quality threshold is defined in terms of a "single A" credit assessment (meaning "A–" by Fitch or S&P; or "A3" by Moody).¹³ The Eurosystem considers a probability of default (PD) over a one-year horizon of 0.10% as equivalent to a "single A" credit assessment. Prudential information can be used by the Eurosystem as a basis for rejecting assets. In countries in which RMBDs are mobilized, the respective national central bank must implement a credit assessment framework for this type of asset. The performance of the credit assessment systems is reviewed annually. It consists of an ex post comparison of the observed default rate for the set of all eligible debtors and the credit quality threshold defined by the benchmark PD.

Risk control measures are applied to protect the Eurosystem against the risk of a financial loss if underlying assets have to be realized owing to the default of a counterparty. The following measures are applied: (i) valuation haircuts (increasing with the maturity and illiquidity of the asset); (ii) margin calls (i.e., marking to market): if the value of the underlying collateral falls below a certain level, the national central bank will require the counterparty to supply additional assets or cash. The Eurosystem may apply limits to the exposure vis-à-vis issuers/debtors or guarantors, and may exclude certain assets from use in its monetary policy operations. The last two are, however, currently not applied.¹⁴

In pooling systems, the counterparty makes a pool of sufficient underlying assets available to the national central bank to cover the related credits, thus implying that individual assets are not linked to specific credit operations. In an earmarking system, each credit operation is linked to specific identifiable assets. Assets are subject to daily valuation.

¹³As of October 25, 2008, and until December, 2009, the ECB lowered the threshold to BBB– (except for asset-backed securities, which were still A–).

¹⁴Additional haircuts will be applied to all newly eligible marketable assets.

TABLE B.I
BALANCE SHEET OF THE EUROSYSTEM ON JUNE 29, 2007^a

Assets		Liabilities	
1. Net Foreign Assets	325,703	5. Banknotes	630,777
2. Net Assets Denominated in EUR	282,041	6. Current Accounts	194,530
3. Liquidity Providing Open Market Operations	463,501	7. Government Deposits	69,621
4. Marginal Lending Facility	5	8. Deposit Facility	80
		9. Other	176,242
Total Assets	1,071,250	Total Liabilities	1,071,250

^aValues in million EUR.

B.3. Liquidity Demand and Supply

To put the liquidity auctions of the ECB into perspective and understand the supply policy of the ECB, let us first look at the simplified balance sheet of the Eurosystem, for example, on June 29, 2007 (Table B.I and Table B.II).

On the Liabilities side, the main items are Banknotes and Current Accounts (together representing 77% of total Liabilities), the latter including the minimum reserve requirement. On the Assets side, there are two large items: Net Foreign Assets and Net Assets Denominated in Euro (representing 56% of total Assets). The former relates to foreign exchange reserve holdings of the Eurosystem (in gold and U.S. Dollar) managed by the ECB. The latter reflects the investment portfolio holdings of national central banks (managed in a decentralized manner according to agreed rules). It is important to note that this is not a monetary policy portfolio. Liquidity-providing OMO represent 43% of the Assets of the Eurosystem. This is the item that is adjusted/managed by the ECB and relevant for monetary policy implementation.

The liquidity needs of the banking system can be calculated from the balance sheet as follows:

TABLE B.II
STRUCTURE OF THE BALANCE SHEET OF THE EUROSYSTEM ON JUNE 29, 2007

Assets	%	Liabilities	%
1. Net Foreign Assets	30	5. Banknotes	59
2. Net Assets Denominated in EUR	26	6. Current Accounts	18
3. Liquidity Providing Open Market Operations	43	7. Government Deposits	6
4. Marginal Lending Facility	0	8. Deposit Facility	0
		9. Other	16
Total Assets	100	Total Liabilities	100

TABLE B.III
SIMPLIFIED BALANCE SHEET OF THE EUROSISTEM ON JUNE 29, 2007^a

Assets	%	Liabilities	%
1. Outright Portfolio	538,125	3. Reserve Base	825,307
2. Repo Operations	463,501	4. Net Standing Facilities	75
		5. Other	176,242
Total Assets	1,001,624	Total Liabilities	1,001,624

^aValues in million EUR.

+ Assets (other than 3 and 4) provide liquidity;

– Liabilities (other than 8) create liquidity needs.

Thus:

Liquidity Deficit = Autonomous Factors (AF) + Current Accounts (CA),

where:

Autonomous Factors (AF) = Net Foreign Assets (NFA) + Net Assets Denominated in Euro (NDA) – Banknotes (BN) – Government deposits (GOV) – Other (O).

Current Accounts include the reserve requirement (RR) plus very small excess reserves (XR).

EXAMPLE 1: From the balance sheet data (Table B.I), we can see that $AF = -268,896$ million EUR, and $CA = -194,530$ million EUR. Therefore, the aggregate liquidity deficit in the euro area was $AF + CA = -463,426$ million EUR or approximately 463 billion EUR, of which 58% was due to the so-called autonomous factors and 42% was due to the reserve requirement (current accounts).

Alternatively, one could express the liquidity needs as follows (Table B.III): $\text{Outright portfolio} - \text{Reserve Base} - \text{Other} = -463,426$ million EUR, where $\text{Reserve Base} = \text{Banknotes} + \text{Current Accounts}$ and $\text{Outright Portfolio} = \text{NFA} + \text{NDA} - \text{GOV}$.

As shown in Table B.I (also Table B.III), the ECB provides liquidity to the banking system mainly via its regular *open market operations*, which satisfy¹⁵

$$\text{OMO} + \text{ML} - \text{DF} = \text{AF} + \text{CA}.$$

And

$$\text{OMO} = \text{MRO} + \text{LTRO}.$$

Before the turmoil, the MROs represented about 70% of the refinancing and the LTROs only 30%. Thus, the bulk of the liquidity was provided by MROs

¹⁵The provision of liquidity via the marginal lending facility is negligible.

on a short-term basis (weekly) and was rolled-over every week. For example, on June 29, 2007, the outstanding volumes in OMO consisted of: (i) main refinancing operations (MROs: 313,499 million EUR) and (ii) longer-term refinancing operations (LTROs: 150,002 million EUR).

In general, the liquidity policy of the ECB is quantity-oriented even if the objective is to steer the overnight interest rate. It is a rules-based approach where the benchmark allotment plays a central role.

The benchmark allotment in a MRO is the allotment amount that allows counterparties to smoothly fulfill their reserve requirements until the day before the settlement of the next MRO, when taking into account the following liquidity needs:

- liquidity imbalances that have occurred previously in the same reserve maintenance period and which were not anticipated in the preceding MRO
- ECB's forecast of the autonomous factors
- ECB's forecast of excess reserves which are assumed to be the same on each day of the reserve maintenance period.

The weekly benchmark allotment is (in simplified terms) given by

$$\begin{aligned} \text{MRO}^{\text{benchmark}} = & \text{AF}^{\text{forecast}} + \underline{\text{RR}} + \text{XR}^{\text{forecast}} \\ & + \{\text{Forecast error of previous week}\}, \end{aligned}$$

assuming $\text{ML} - \text{DF} = 0$. The reserve requirement is fixed, as it is calculated on a lagged accounting basis.

The underlying idea of the benchmark allotment is that if the ECB's forecast errors are unbiased and the forecast error variance is small compared to the reserve requirement, then the overnight rate on the last day in the reserve maintenance period should be expected to be close to the middle of the interest rate corridor defined by the rates on the standing facilities. With a symmetric interest rate corridor, this policy should keep the overnight rate close to the policy rate.

In fact, on the last day of the reserve maintenance period, we get the aggregate liquidity imbalance equal to the forecast error made by the ECB, the former being either a net recourse to marginal lending (liquidity shortage) or to the deposit facility (liquidity surplus):

$$\text{ML} - \text{DF} = \text{Forecast Error}.$$

If the overnight rate is expected to be close to the policy rate on the last day of the RMP, then, on any other day in the reserve maintenance period, it should also be close to the policy rate by applying the martingale hypothesis.

Empirical evidence before the turmoil matches these predictions very closely (Figure B.1).

Figure B.4 shows that the liquidity needs of the banking system evolved very smoothly before the turmoil between 400 and 450 billion EUR. The MROs

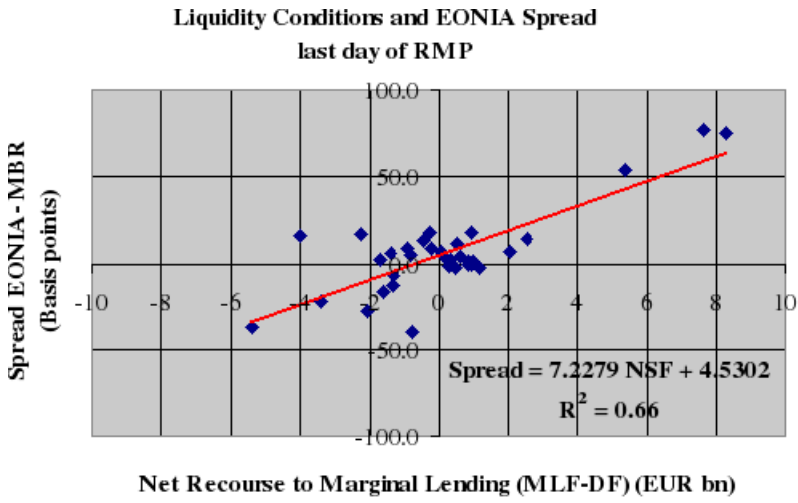


FIGURE B.1.—EONIA spread and liquidity conditions on the last day of the RMP.

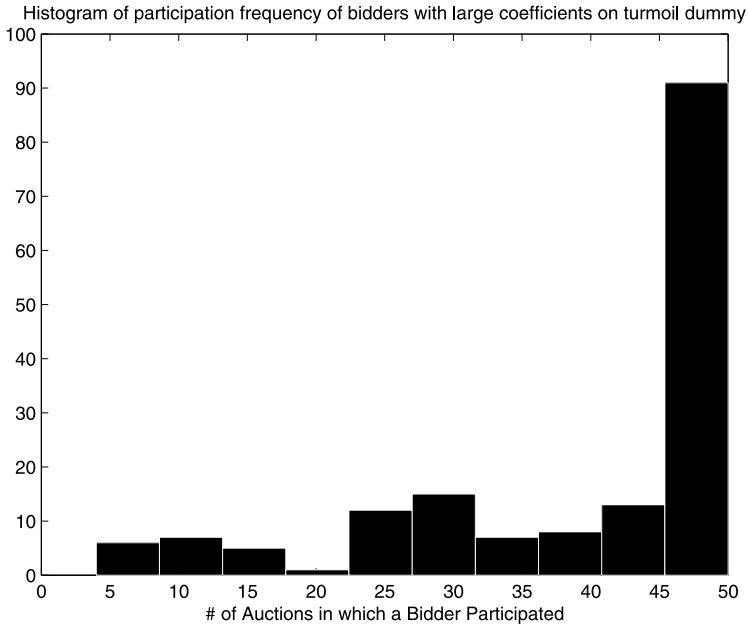


FIGURE B.2.—Histogram of participation by bidders with large significant turmoil effects.

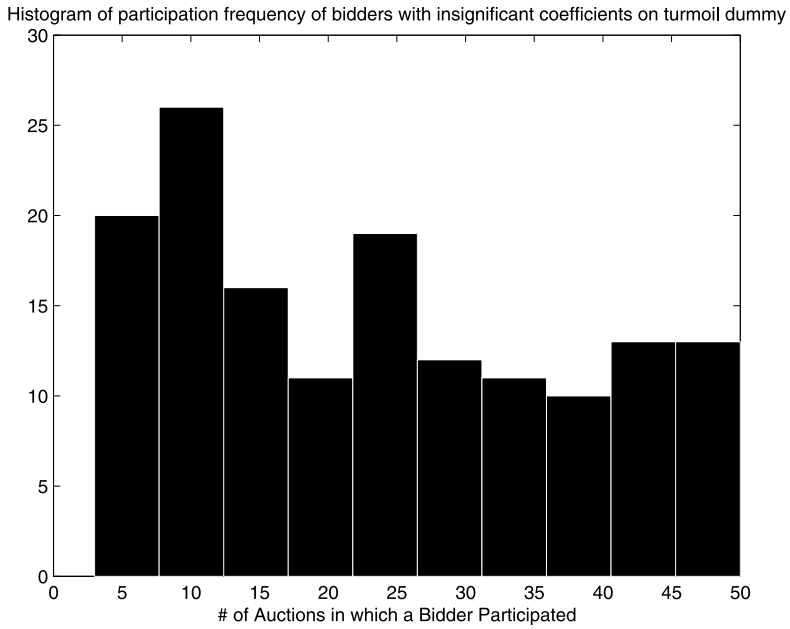


FIGURE B.3.—Histogram of participation by bidders with insignificant turmoil effects.

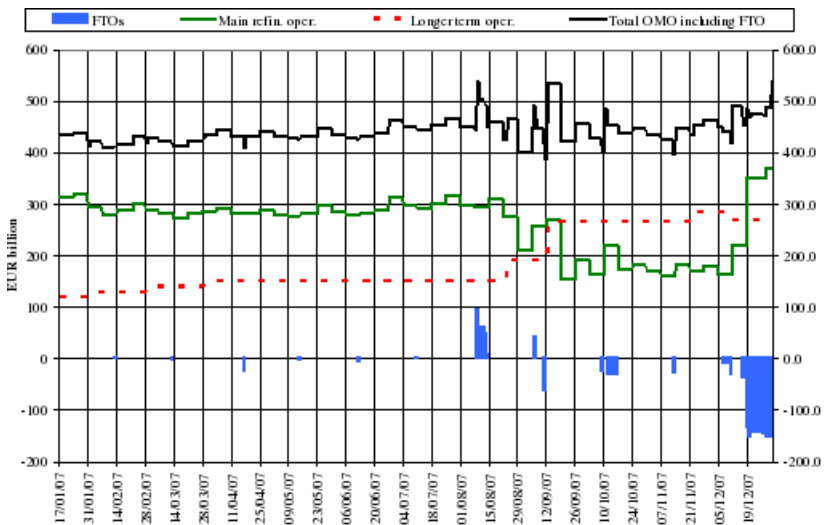


FIGURE B.4.—Liquidity provision by the ECB in 2007.

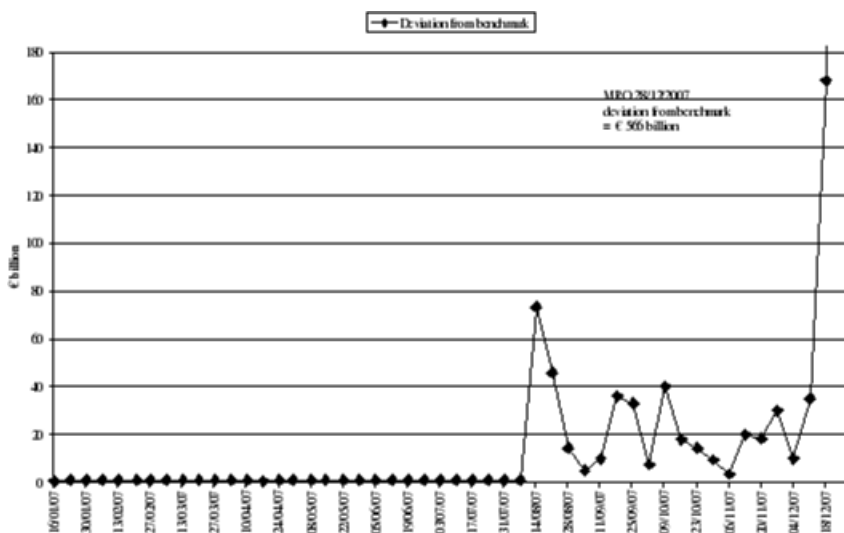


FIGURE B.5.—Deviation from benchmark at the MROs in 2007.

had a volume of around 300 billion EUR and the LTROs about 100–150 billion EUR. Deviations from benchmark were negligible, as illustrated in Figure B.5.

Figure B.4 further illustrates how the ECB managed liquidity during the turmoil. Four aspects are shown: (i) the total volume of refinancing was kept on trend, albeit with somewhat more volatility; there was a significant increase at the end of the year, mainly for seasonal reasons; (ii) there was an increase in the absolute volume and relative weight of LTROs in total refinancing; however, the volume of MROs declined so that the total volume was kept on trend; (iii) the ECB conducted more frequent and sizable fine-tuning operations (FTOs), both providing and draining liquidity; the latter (draining) were more frequent and sizable; (iv) a final aspect is illustrated in Figure B.5: at the MROs, deviations from benchmark became very sizable and time-varying (larger at the first MRO in the RMP and somewhat smaller in subsequent MROs in the same RMP).

B.4. Calculation of Reserve Deficiencies

A bank's reserve deficiency varies with unexpected liquidity shocks, which may be driven by unexpected mismatches between cash inflows and outflows from that bank's accounts; it may also reveal the failure to guarantee a targeted allotment at a previous auction. The Deficiency variable is calculated for each bank i as follows. First:

$$D_{it} = T * RR_i - \sum_{s=1}^t CA_{is},$$

where D_{it} is the accumulation of reserves needed to fulfill its requirement until the last day of the reserve maintenance period for bank i on day t . RR_i is the daily average reserve requirement of bank i (set by the ECB at the beginning of each reserve maintenance period) and T is the number of days in the maintenance period; $T - t$ is the number of days until the end of the reserve maintenance period. If a bank follows a smooth (linear) reserve fulfilment path, it targets as its daily current account the daily average reserve requirement D_{it}^* :

$$D_{it}^* = T * RR_i - t * RR_i \quad \Leftrightarrow \quad \frac{D_{it}^*}{RR_i} = T - t.$$

Deficiency is therefore defined as

$$\text{Deficiency}_{it} = \frac{D_{it}}{RR_i} - \frac{D_{it}^*}{RR_i} = \frac{D_{it}}{RR_i} - (T - t).$$

We use the Deficiency value on the day before the MRO. To account for the potential nonlinearity around 1 (Deficiency = 1 means that a bank needs exactly its daily reserve requirement for the rest of the monitoring period to satisfy the monthly requirement), we also introduce a dummy variable for “Small Deficiency” and we interact it with our Deficiency measure.

B.5. Long-Term Refinancing Operations

We also obtained data on ECB’s LTROs. We have 19 auctions covering 10/2006 to 3/2008. As described in the institutional background, these auctions are run only once a month and they are for loans with 3-month maturity. These data are summarized in Table B.IV, and the pre- and post-turmoil means and standard deviation in Table B.V. The patterns, in general, correspond to those from the main refinancing operations studied in the main body of this paper. The important differences are (i) the much starker increase in the price bid spread against the EONIA rate following the turmoil (from 1 to 47 basis

TABLE B.IV
SUMMARY STATISTICS—LTROs (19 AUCTIONS)

	Mean	St. Dev.	Min	Max
Bidders	148	19	96	175
Submitted steps	2.29	1.68	1	10
Price bid	4.20	0.44	3.20	5.05
Price bid spread ^a	0.26	0.26	−0.48	1.02
Quantity bid	0.01	0.02	$1 * 10^{-5}$	0.28
Issued amount (billions €)	49.74	8.58	40	75

^aSpread against EONIA rate.

TABLE B.V
SUMMARY STATISTICS—LTROS: BEFORE AND AFTER AUGUST, 2007

	Mean		St. Dev.	
	Before	After	Before	After
Bidders	150.6	143.4	10.66	26.53
Submitted steps	1.76	3.04	0.94	2.15
Price bid	3.78	4.55	0.26	0.16
Price bid spread ^a	0.01	0.47	0.02	0.17
Quantity bid	0.009	0.013	0.024	0.023
Issued amount (billion €)	46.36	54.38	5.05	9.82

^aSpread against EONIA rate.

points), which is about five times the increase in the MROs, and (ii) the number of participants is less than half of those in MROs. This is probably mainly due to the overlapping maturities of the loans (monthly auction frequency and 3-month maturity), since the set of banks participating in both types of refinancing operations is very similar. This last observation allows us to perform the same exercise as in the case of MROs and use the estimated values to classify bidders into more and less distressed groups. Doing so, we obtain a similar pattern as in the MROs: only about $\frac{2}{3}$ of bidders experienced an increase in their mean (quantity-weighted) marginal value, while almost all banks significantly increased their bid spreads against EONIA, suggesting more aggressive bidding strategy.

Following the same procedure as in MROs, we estimated the marginal values that would rationalize the observed bids in LTROS. We also repeated the same exercise as in the case of MROs to classify the bidders in LTROS into the distressed and not distressed groups. The results are summarized in Table B.VI. Due to less participation frequency (we have only 11 auctions pre-turmoil and 8 auctions post-turmoil), we were able to classify only 200 bidder identities. A very similar pattern arises for those, however, as in the case of MROs. Virtually all participants significantly increased their bids, but for $\frac{49}{189}$ (or 26%) of those, this does not seem to have been accompanied by an increase in values.

TABLE B.VI
PREDICTING POTENTIAL PROBLEMS—LTROS

Based on	Bids	
	Yes	No
Values	Yes	140
	No	49

REFERENCE

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