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The price of liquidity: the effects of market conditions and bank characteristics

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EUROPEAN CENTRAL BANK

EUROSYSTEM

ECB LAMFALUSSY FELLOWSHIP
PROGRAMME

WORKING PAPER SERIES

NO 1376 / SEPTEMBER 2011

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LIQUIDITY**

**THE EFFECTS OF
MARKET CONDITIONS
AND BANK
CHARACTERISTICS**

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THE PRICE OF LIQUIDITY THE EFFECTS OF MARKET CONDITIONS AND BANK CHARACTERISTICS¹

by Falko Fecht², Kjell G. Nyborg³
and Jörg Rocholl⁴



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ABSTRACT

We study the prices that individual banks pay for liquidity (captured by borrowing rates in repos with the central bank and benchmarked by the overnight index swap) as a function of market conditions and bank characteristics. These prices depend in particular on the distribution of liquidity across banks, which is calculated over time using individual bank-level data on reserve requirements and actual holdings. Banks pay more for liquidity when positions are more imbalanced across banks, consistent with the existence of short squeezing. We also show that small banks pay more for liquidity and are more vulnerable to squeezes. Healthier banks pay less but, contrary to what one might expect, banks in formal liquidity networks do not. State guarantees reduce the price of liquidity but do not protect against squeezes.

JEL classification: G12, G21, E43, E58, D44

Keywords: Banks, Liquidity, Money markets, Repos, Imbalance

Non-technical summary

The recent financial crisis has brought to light the importance of the market for liquidity for the broader financial markets. For example, as testified by the then Secretary of the Treasury, Henry M. Paulson Jr., and the Chairman of the Federal Reserve Board, Ben Bernanke, before the US House Financial Services Committee, September 23, 2008, during the crisis, the entire global banking and financial system was put at risk as liquidity was drying up.¹ If turmoil in the market for liquidity can bring the global financial system to its knees, then it is important to enhance our understanding of this market. In this paper, we contribute by studying at a disaggregated level the prices that banks pay for liquidity. Using data from before the recent crisis, we show how market conditions and individual bank characteristics impact on these prices.

The paper finds that the price of liquidity systematically depends on bank characteristics and market conditions. Specifically, we have the following five results: First, a more imbalanced, or dispersed, distribution of liquidity across banks leads to more aggressive bidding and higher prices paid. Furthermore, the premium paid per unit that a bank is short is increasing in imbalance. Second, banks pay more for liquidity as their financial health deteriorates. Third, larger banks pay less. Furthermore, a more imbalanced distribution of liquidity increases the extra cost of liquidity to smaller banks. Thus, smaller banks seem to be more vulnerable to liquidity squeezes. Fourth, institutions that are part of formal liquidity networks pay more than other institutions, unless they also have government guarantees, in which case they pay the same. Thus, formal liquidity networks do not work well for all member institutions. Fifth and finally, government guarantees reduce the price a bank pays for liquidity, on average, but do not protect against squeezes.

The findings in this paper potentially have wide implications. Insofar as conditions in the market for liquidity are transmitted to the broader financial markets, tightening in the interbank market arising from imbalances or worsening financial health could have systemic risk and asset pricing relevance as well as contribute towards commonality in liquidity across different securities and asset classes.

¹See, e.g., <http://blogs.wsj.com/economics/2008/09/23/bernanke-testimony-on-financial-markets-andgovernment-bailout/>

1. Introduction

The recent financial crisis has brought to light the importance of the market for liquidity for the broader financial markets. For example, Secretary of the Treasury Henry M. Paulson Jr. and Chairman of the Federal Reserve Board Ben Bernanke testified before the US House Financial Services Committee on September 23, 2008, that the entire global banking and financial system was put at risk as liquidity was drying up.¹ If turmoil in the market for liquidity can bring the global financial system to its knees, then it is important to enhance our understanding of this market. In this paper, we contribute by studying at a disaggregated level the prices that banks pay for liquidity, captured here by borrowing rates in repos with the central bank and benchmarked by the overnight index swap. Using data from before the recent crisis, we show how market conditions and individual bank characteristics impact on these prices.

Our primary focus is on the hypothesis that the distribution of liquidity across banks matters (Bindseil, Nyborg, and Strebulaev, 2009) and, especially, on the idea that a more imbalanced, or dispersed, distribution of liquidity leads to a tighter market in which banks with liquidity shortfalls risk being squeezed or rationed by banks that are long (Nyborg and Strebulaev, 2004).² We find support for this idea. More generally, our findings show that the price a bank pays for liquidity is affected by the liquidity positions of other banks, as well as its own. This stands in contrast to a large swathe of asset pricing theory, in which the distribution of an asset across agents is not a concern.

In our analysis of liquidity positions and imbalances, we control for bank-specific characteristics; specifically, financial health, size, and type. These are also interesting to study in their own right and give rise to four additional hypotheses that we test. First, financially unhealthy banks are likely to face tighter conditions in the interbank market, which we expect to translate into higher prices. Second, there could be an advantage to size, for example because larger banks are more diversified and thus could be less exposed to

¹See, e.g., <http://blogs.wsj.com/economics/2008/09/23/bernanke-testimony-on-financial-markets-and-government-bailout/>.

²Related to this idea, Furfine (2000) finds evidence that a link exists between interbank payment flows and the federal funds rate.

liquidity shocks (Kashyap, Rajan, and Stein, 2002). They could also have better access to interbank markets, through having larger networks of regular counterparties or possessing a wider range of collateral. Scale also affects the incentives to put resources into liquidity management. Larger banks have more to gain from a per unit reduction in the price of liquidity. Allen, Peristiani, and Saunders (1989) provide empirical evidence of differences in purchase behavior among differently sized banks in the federal funds market (see also Furfine, 1999). In the euro area, Nyborg, Bindseil, and Strebulaev (2002), Linzert, Nautz, and Bindseil (2007), and Craig and Fecht (2007) present evidence suggesting that large banks pay less, but they do not control for banks' liquidity positions.

Third, bank type could matter, for example because different types of financial institutions have different relationship networks to help overcome frictions in the interbank market (Freixas, Parigi, and Rochet, 2000). Empirical support for this idea is provided by Furfine (1999) and Cocco, Gomes, and Martins (2009). Ehrmann and Worms (2004) suggest that formal liquidity networks, such as what we find among savings and cooperative banks in Germany, can help banks overcome disadvantages from being small. Fourth and finally, some bank types in our sample have governmental guarantees with respect to the repayment of their loans, which we would expect to reduce credit risk and thus the price these banks would have to pay for liquidity.

In practice, liquidity can be obtained through numerous types of contracts, varying in the degree and type of collateralization, tenor, and type of counterparty. Our price data come from repos with the central bank. Specifically, we study the prices, or rates, German banks pay for liquidity in the main refinancing operations of the European Central Bank (ECB). These are the most significant sources of liquidity in the euro area.³ During the sample period, June 2000 to December 2001, the average operation injected 84 billion euros of two-week money, against a broad set of collateral.⁴ Over the crisis period, other

³See, e.g., European Central Bank (2002a or 2002b) for further information. See Hartmann and Valla (2008) for an overview of the euro money markets.

⁴Eligible collateral includes, but is not limited to, government bonds and covered bank bonds. See European Central Bank (2001) for detailed information regarding the various types of collateral that could be used in ECB main refinancing operations during the sample period.

central banks such as the Federal Reserve System and the Bank of England introduced similar operations to allow banks to obtain liquidity against an expanded set of collateral.

Unique to this paper, we have data on banks' reserve positions relative to what they are required to hold with the central bank. Thus we can measure the extent to which banks are short or long liquidity and thereby also get a gauge on money market imbalances.

Five other features of our data set make it ideal for studying variations in the prices banks pay for liquidity. First, during the sample period, the ECB's main refinancing operations are organized as discriminatory price auctions. Thus, different banks pay different prices, as a function of their bids. Second, these operations are open to all credit institutions in the euro area. Third, for each operation, we have all bids and allocations of all institutions from the largest euro area country (Germany). Fourth, individual bank codes allow us to control for bank-specific characteristics. Fifth, all liquidity obtained in the operations have the same tenor (two weeks). Thus, because each operation provides us with a comprehensive set of bids and prices for collateralized loans of identical maturity at one time, we have a clean setting for studying the willingness to pay and the actual prices paid for liquidity by different banks.

Our analysis has three key elements. First, for each bidder in each operation, we calculate the quantity-weighted average rate bid and paid, respectively, benchmarked by the contemporaneous two-week Eonia swap (the euro overnight index swap). Second, for each bank, whether bidding or not, we also calculate its size-normalized liquidity position at the time of each operation, based on the bank's reserve requirements, reserve fulfillment, and maturing repo from the operation two weeks back. Motivated by the theoretical results of Nyborg and Strebulaev (2004), we then calculate the liquidity imbalance as the standard deviation of the liquidity positions across all German banks. The theoretical prediction is that bidding is more aggressive and prices are higher as imbalance increases because of a larger potential for short squeezing. Third, we test this prediction by running panel regressions with and without a Heckman sample selection correction, taking into account individual banks' liquidity positions and other characteristics.

The findings for the five hypotheses can be summarized as follows. First, consistent with the theory, an increase in imbalance leads to more aggressive bidding and higher

prices paid. Furthermore, the premium paid per unit that a bank is short is increasing in imbalance. Second, banks pay more for liquidity as their financial health deteriorates. Third, larger banks pay less. Furthermore, as imbalance increases, so does the extra cost of liquidity to smaller banks. Thus, smaller banks seem to be more vulnerable to liquidity squeezes.⁵ Fourth, institutions that are part of formal liquidity networks pay more than other institutions, unless they also have government guarantees, in which case they pay the same. Thus, formal liquidity networks do not work well for all member institutions. Fifth, government guarantees reduce the price a bank pays for liquidity, on average, but do not protect against squeezes.

To get a sense of magnitudes in this market, the average auction has a price differential between the highest and lowest paying banks of 11.5 basis points (bps). On average, the 5% smallest banks pay in excess of two basis points more than the 1% largest banks. By way of comparison, the average conditional volatility of the two-week interbank rate on main refinancing operation days is 5.3 bps. One basis point of the average operation size of 84 billion is equivalent to approximately 8.4 million euros on an annualized basis. For the German bank with the largest (smallest) reserve requirement, 1 bp translates into approximately 290,000 (20) euros on an annualized basis. Thus, for large banks, the difference between paying the most or the least is a substantial sum, while for small banks it is not (at least not individually).

Our findings potentially have wide implications. Insofar as conditions in the market for liquidity are transmitted to the broader financial markets, tightening in the interbank market arising from imbalances or worsening financial health could have systemic risk and asset pricing relevance, perhaps along the lines modeled by Allen and Gale (1994, 2004) or Brunnermeier and Pedersen (2005, 2009), and contribute toward commonality in liquidity across different securities and asset classes (Chordia, Subrahmanyam, and Roll, 2000; Hasbrouck and Seppi, 2001; Huberman and Halka, 2001; and Chordia, Sarkar, and Subrahmanyam, 2005). Support of this view is provided by Nyborg and Östberg (2010), who

⁵These results point to a potential source of competitive advantage of size in banking and thus relate to the banking literature on the advantages and disadvantages of size. See, e.g., Peek and Rosengren (1998), Berger and Udell (2002), Sapienza (2002), and Berger, Miller, Petersen, Rajan, and Stein (2005).

find that tight interbank markets are associated with systematic stock market volume and price effects.

The possibility of being squeezed or rationed could reduce banks' propensity to extend credit and thereby adversely affect the real economy. Evidence exists that the recent turmoil led to reduced lending by banks to corporations (Ivashina and Scharfstein, 2010) and retail borrowers (Puri, Rocholl, and Steffen, 2010), which in the latter work is shown to be particularly due to a reduction in lending by liquidity-strapped banks. Acharya, Gromb and Yorulmazer (2009) argue that squeezed banks could also have to liquidate existing loans, which could be inefficient.⁶

The rest of this paper is organized as follows. Section 2 provides institutional background on reserve requirements and the main refinancing operations. It also describes our data sets. Section 3 defines bank-level variables, including liquidity status, and presents some descriptive statistics. Section 4 studies the data cross-sectionally. Section 5 presents the panel analysis and provides the main results of the paper. Section 6 concludes. The Appendix contains an overview of the structure of the German banking sector.

2. Reserve requirements, repo auctions, and data

In this section, we describe the institutional setting and the data that we use for our analysis.

2.1. Reserve requirements and repo auctions

According to ESCB (European System of Central Banks) regulation, all euro area credit institutions, including subsidiaries and branches of foreign banks, are subject to a minimum reserve requirement. The required reserves have to be held as average end-of-

⁶Acharya, Gromb, and Yorulmazer argue that such inefficient liquidations provide a rationale for the public provision of liquidity by a central bank. Related to this, Bhattacharya and Gale (1987) argue that banks have a propensity to underinvest ex ante in liquid assets because they prefer others to bear that cost. See also Bryant (1980), Diamond and Dybvig (1983), Donaldson (1992), Bhattacharya and Fulghieri (1994), and Allen and Gale (2000).

business-day balances over the maintenance period on account with the national central bank.⁷ During the sample period of this paper, reserve maintenance periods had a length of one month, starting on the 24th of each month and ending on the following 23rd, and German banks accounted for around 30% of total reserve requirements in the euro zone.

The basis for the calculation of a bank's reserve requirement is its end-of-calendar-month short-term liabilities held by nonbanks or banks outside the euro area two months before the beginning of the current maintenance period.⁸ For example, a bank's reserve requirements for the maintenance period starting May 24 are determined by its short-term liabilities on March 31. The minimum reserve requirement is 2% of these liabilities. Compliance with reserve requirements is a hard constraint. Unlike in the US, these cannot be rolled over into the next maintenance period.⁹ Hence, once we have arrived at a given maintenance period, reserve requirements are fixed. They can be viewed as exogenous for the purpose of analyzing operations in that maintenance period.

The main source of reserves are the ECB's main refinancing operations (or repo auctions). These are held once a week. Thus there are up to five operations within each reserve maintenance period. The funds obtained in these operations have a tenor of two

⁷Required reserve holdings are remunerated at the average stop-out rate of the ECB main refinancing operations, during the respective maintenance period. Excess reserves can be transferred to the deposit facility, which is always 100 basis points below the operations' minimum bid rate during the sample period. The ECB also operates with a marginal lending facility, where banks can borrow against collateral at a rate that is 100 basis points above the minimum bid rate in the auction during the sample period.

⁸Specifically, these are overnight deposits, deposits with an agreed maturity up to two years, deposits redeemable at notice up to two years, and issued debt securities with agreed maturity up to two years.

⁹If a bank fails to hold sufficient reserves, for example, because it does not make up a reserve shortfall at the marginal lending facility, the ECB can impose any of the following sanctions. It can require payment of up to 5 percentage points above the marginal lending rate or up to two times the marginal lending rate on the difference between the required and the actually held reserves. Furthermore, the ECB can call for the provision of non-interest-bearing deposits up to three times the amount the respective bank failed to provide for. The maturity of those deposits must not exceed the period during which the institution failed to meet the reserve requirement. The ECB can impose additional sanctions if an institution repeatedly fails to comply with the reserve requirement. For a more detailed description of the Eurosystem's minimum reserve system, see European Central Bank (2005).



weeks during the sample period.¹⁰ Each operation is timed to coincide with the maturity of funds obtained in the second-to-previous operation. The schedule of operations in a given year is announced three months before the start of the year. Typically, the operations are scheduled for Tuesdays at 9:30 a.m., with terms being announced on Mondays at 3:30 p.m. Results are announced on the auction day at 11:20 a.m. Winning bids are settled the following business day. The operations are open to all banks in the European Monetary Union that are subject to reserve requirements.

In each operation, or auction, each bidder can submit up to ten bids, which are rate-quantity pairs for two-week money. The tick size is 1 basis point and the quantity multiple is 100,000 euros. There are no noncompetitive bids. There is a preannounced minimum bid rate. This rate is determined at the meetings of the ECB's Governing Council, normally held on the first and third Thursday of each month during the sample period. The minimum bid rate was changed six times during the sample period.¹¹

The ECB has a liquidity neutral policy; that is, it aims to inject through its operations the exact quantity of liquidity that banks need to satisfy reserve requirements in aggregate. When it announces a main refinancing operation, the ECB also publishes an estimate of liquidity needs for the entire euro area banking sector for the following week, thus providing bidders with an unbiased estimate of the auction size. We refer to this liquidity neutral amount as the expected auction size. Deviations could occur because of the lag between the auction announcements (Mondays at 3:30 p.m.) and the allotment decision (Tuesdays at 11:20 a.m.), during which time the ECB could have updated its forecast of the banking sector's liquidity needs.¹² However, deviations tend to be very small, averaging less than

¹⁰Once a month, the ECB also holds longer-term refinancing operations with three-month maturities (see Linzert, Nautz, and Bindseil, 2007). The ECB could also hold nonregular, fine-tuning operations with nonstandard maturities, for example, overnight, but none occurred during the sample period.

¹¹It started out at 4.25%, changed to 4.5% in time for the September 5, 2000 auction, then increased to 4.75% in time for the October 11, 2000 auction, fell back to 4.50% for the auctions held on and after May 14, 2001, fell further to 4.25% for the auction on and after September 4, 2001, to 3.75% on September 18, 2001 and to 3.25% on November 13, 2001, at which level it remained until the end of the sample period.

¹²Deviations from the expected auction size also occur in a few instances in which banks in aggregate demanded less than the liquidity neutral amount, speculating on decreases in the minimum bid rate in

1% of the preannounced liquidity neutral amount. Thus, banks face little aggregate supply uncertainty in the main refinancing operations. However, the liquidity neutral policy also means that if one bank is long liquidity, another must be short. Thus this policy could increase the potential for banks being able to exercise market power over marginal units.

2.2. *Data*

Our analysis makes use of four data sources supplied by the Bundesbank. First, we have the complete set of bids made by German registered financial institutions, broken down by bidder, in all 78 ECB repo auctions (main refinancing operations) in the period June 27, 2000 to December 18, 2001. This covers 18 reserve maintenance periods. The number of German bidders in an auction varies from 122 to 546.

Second, we have reserve data from all 2,520 German registered financial institutions in the period May 2000 to December 2001 that were required to hold reserves with the central bank as of December 2001. The reserve data cover 842 bidders in the main refinancing operations and 1,678 nonbidders. A bidder is defined as a bank that bids at least once and, therefore, appears in the auction data set. The reserve data consist of each institution's cumulative reserve holdings within the maintenance period, as well as its marginal reserve holding, at the end of each business day preceding an auction. In addition, we have each institution's reserve requirement for each maintenance period over the sample period. The reserve data are not available for 518 institutions that ceased operating as stand-alone entities during the sample period. Seventeen of these submitted bids in the auctions.

Third, we have end-of-month balance sheet data for each bank. German banks are required to report balance sheet statistics to the Bundesbank on a monthly basis. As a measure of size, we thus use the book value of a bank's total assets at the end of each calendar month.

Fourth, we have yearly income statements, from which we obtain write-offs and provisions and return on assets for each bank. The third financial health variable, the equity ratio, is calculated from the balance sheet data on a monthly basis.

time for the next auction in the maintenance period.

Unique bank codes allow us to track banks over time and correlate bidding decisions with characteristics such as size, financial health, and fulfillment of reserves. The complete bidding data consist of 59,644 individual bids and 25,345 individual demand schedules from 859 bidders. Deleting the bids from the 17 bidding banks for which we do not have reserve data reduces this to 59,156 individual bids and 25,120 individual demand schedules from 842 different bidders. We lack balance sheet data on seven bidders, taking the number of bidders for which we have complete data down to 835.

The data set is pruned further as follows. First, we exclude 45 banks that are registered with zero reserve requirement in every maintenance period during the sample period. Second, we throw out two extreme outliers. The first is a nonbidder that has an average reserve fulfillment (relative to required reserves) of 190,926%. The second is a bidder with an average reserve fulfillment of 3,011%. Without this bank, the average fulfillment of private bidding banks is 100.25%; with this bank, the average is 131.8%. This takes the data set down to 834 bidders and 1,632 nonbidders. Third, we exclude Bausparkassen and special purpose banks (14 institutions).¹³ The analysis below is thus carried out on a final set of 820 bidders (and 23,673 individual demand schedules) and 1,632 nonbidders.

3. Univariate analysis of bank-level variables

We start our analysis by studying bank-level variables with respect to liquidity status, financial health, and size as well as pricing and bidding. To calculate money market imbalance, we first need to measure individual banks' liquidity status. Summary statistics are presented by bank type, because savings banks and cooperatives are part of formal liquidity networks and also have different ownership structures than private banks (see the Appendix for details). Within each bank category, we differentiate between bidders (banks that bid in at least one operation in our data set) and nonbidders to get a first

¹³These institutions have very low reserve requirements, averaging to around 0.1% of total assets. This is substantially lower than for other banking sectors, reflecting that they have different functions than typical banks. The Bausparkassen sector also includes several extreme outliers with respect to reserve fulfillment.

look at the extent to which liquidity status matters, here with respect to the decision to participate in the main refinancing operations.

3.1. *Liquidity status and financial health: definitions*

To measure banks' liquidity status, we define the variables *fulfillment* and *normalized net excess reserves*. These are different ways of gauging the extent to which a bank is short or long reserves going into an auction.

Fulfillment is a bank's cumulative reserve holdings as a percentage of its cumulative required reserves, within a reserve maintenance period.

$$\text{fulfillment}_{ijp} = \frac{\text{cumulative holding}_{ijp}}{\text{cumulative required reserves}_{ijp}} \times 100, \quad (1)$$

where i refers to the bank; j , to the auction; and p , to the reserve maintenance period. Multiplying by 100 means that we express fulfillment as a percentage. The fulfillment is measured for each bank using reserve data at the close of business the day before each auction. A fulfillment of 100% means that the bank has held reserves thus far in the maintenance period with a daily average exactly equal to the average daily requirement the bank faces this period. Thus, a fulfillment of less (more) than 100% indicates that the bank is short (long).

To define normalized net excess reserves, we start with the *gross excess reserves*. This compares the reserves the bank has on deposit with the central bank the evening before the auction with what it needs to hold on a daily basis for the balance of the reserve maintenance period to exactly fulfill reserve requirements.

$$\text{gross excess reserves}_{ijp} = \text{holding}_{ijp} - \text{required remaining daily holding}_{ijp}, \quad (2)$$

where

$$\begin{aligned} \text{required remaining daily holding}_{ijp} \\ = \frac{\text{required total monthly reserves}_{ip} - \text{cumulative holding}_{ijp}}{\text{days left of maintenance period}_{jp}}. \end{aligned} \quad (3)$$

The *net excess reserves* nets out from a bank's holding the loan from two auctions ago that matures at the time of the current auction.

$$\text{net excess reserves}_{ijp} = \text{gross excess reserves}_{ijp} - \text{maturing repo}_{ijp}, \quad (4)$$

where maturing repo_{ijp} is the amount the bidder won in auction $j-2$. Because this amount matures at the time of auction j , the net excess reserves is what the bank needs to borrow in the auction to be even with respect to its reserve requirements. A negative (positive) net excess reserves is indicative of the bank being short (long).

We normalize the net excess reserves for size by dividing it by the average daily required holding:

$$\text{normalized net excess reserves}_{ijp} = \frac{\text{net excess reserves}_{ijp}}{\text{average daily required reserves}_{ip}} \times 100. \quad (5)$$

In a similar way, we also define the *normalized gross excess reserves* by dividing the gross excess reserves by the average daily required reserves.

The normalized net excess reserves measure takes into account not only a bank's fulfillment thus far in the maintenance period, but also its liquidity need going forward, including the need to refinance maturing repos. For this reason, this measure is arguably a better indicator of liquidity need than fulfillment, and we, therefore, use it in the regression analysis. Normalization by required reserves means that the measure is independent of size, allowing us to distinguish between size and pure liquidity status effects. A bank that always has a fulfillment of 100% and borrows in every auction (borrows in no auction) has negative (zero) normalized net excess reserves going into every auction.

We capture a bank's financial health by three variables: (1) write-offs and provisions, measured annually as the write-offs and provisions on loans and securities as a percent of total assets; (2) return on assets (ROA), measured annually as net income as a percent of total assets; and (3) equity ratio, measured monthly as total book equity as a percent of total assets.

3.2. *Liquidity status and other bank characteristics: descriptive statistics*

Table 1 provides summary statistics on bidding banks' liquidity status and other characteristics, broken down into six bank categories: private banks, savings banks, cooperatives, branches of foreign banks, Landesbanks (savings bank head institutions), and cooperative central banks (see the Appendix for details). Table 2 does the same for nonbidding banks, but note that there are no nonbidding Landesbanks or cooperative central banks.

Table 1

Bank characteristics: bidders.

Descriptive statistics on bank characteristic variables for six types of banks as classified by the Deutsche Bundesbank: private banks, savings banks, cooperatives, branches of foreign banks, Landesbanks, and cooperative central banks. Bidders are all banks that participated in at least one main refinancing operation during the sample period (June 27, 2000 to December 18, 2001). The liquidity variables (fulfillment, normalized gross excess reserves, normalized net excess reserves) are calculated for each bank the day before each auction. Asset size and the equity ratio are calculated for each bank each calendar month; reserve requirements for each maintenance period. Write-offs and provisions and return on assets are obtained annually. See Subsection 3.2 for definitions of the variables. For each bank, the mean of each variable is calculated (unconditionally, i.e., not conditional on bidding decisions), thus yielding a sample of individual bank means for each variable. The table reports summary statistics of these means across banks within each bank type.

	Mean	Median	Standard deviation	Standard error	Minimum	Maximum	Observations
<i>Panel A: Private banks</i>							
Assets (millions)	22,794	4,149	52,774	5,472	62	267,591	93
Reserve requirement (daily, millions)	132.43	20.25	438.16	45.44	0.20	2,901.60	93
Fulfillment (percent)	100.25	101.81	15.53	1.61	50.85	157.03	93
Norm gross excess reserves (percent)	14.55	9.42	41.83	4.34	-77.78	244.37	93
Norm net excess reserves (percent)	-243.82	-83.39	530.25	54.98	-3,739.82	212.39	93
Write-offs and provisions (percent)	0.35	0.21	0.48	0.05	0.00	3.08	93
Return on assets (percent)	0.34	0.21	0.47	0.05	-0.98	2.27	93
Equity ratio (percent)	4.96	4.06	3.90	0.40	0.81	24.04	93
<i>Panel B: Savings banks</i>							
Assets (millions)	2,092	1,307	2,754	144	170	31,385	366
Reserve requirement (daily, millions)	22.06	14.31	27.48	1.44	1.26	314.89	366
Fulfillment (percent)	102.65	101.36	6.08	0.32	84.22	133.01	366
Norm gross excess reserves (percent)	7.48	6.05	9.35	0.49	-35.88	40.76	366
Norm net excess reserves (percent)	-81.53	-34.98	126.12	6.59	-1,187.84	25.81	366
Write-offs and provisions (percent)	0.36	0.32	0.22	0.01	0.00	1.48	366
Return on assets (percent)	0.22	0.21	0.11	0.01	-0.04	0.93	366
Equity ratio (percent)	4.12	4.01	0.79	0.04	2.46	8.08	366

Panel C: Cooperatives

Assets (millions)	678	350	1,380	77	26	18,582	324
Reserve requirement (daily, millions)	7.81	4.04	13.25	0.74	0.24	127.10	324
Fulfillment (percent)	102.94	101.49	8.15	0.45	74.05	159.71	324
Norm gross excess reserves (percent)	9.42	5.69	13.17	0.73	-48.10	70.77	324
Norm net excess reserves (percent)	-31.90	-9.14	66.10	3.67	-585.01	44.27	324
Write-offs and provisions (percent)	0.45	0.39	0.46	0.03	0.00	7.22	324
Return on assets (percent)	0.17	0.19	0.23	0.01	-1.53	0.77	324
Equity ratio (percent)	4.94	4.85	1.11	0.06	1.67	11.63	324

Panel D: Foreign banks

Assets (millions)	2,256	1,135	2,586	564	31	8,009	21
Reserve requirement (daily, millions)	17.09	8.94	18.91	4.13	0.02	62.31	21
Fulfillment (percent)	142.30	99.40	139.77	30.50	71.77	685.95	21
Norm gross excess reserves (percent)	103.94	12.67	278.41	60.75	-14.55	965.91	21
Norm net excess reserves (percent)	-206.53	-24.12	663.91	144.88	-1950.78	968.01	21
Write-offs and provisions (percent)	0.26	0.09	0.60	0.13	0.00	2.18	21
Return on assets (percent)	0.28	0.15	0.53	0.12	-0.68	1.45	21
Equity ratio (percent)	7.86	5.02	9.19	2.01	1.09	34.09	21

Panel E: Landesbanks

Assets (millions)	96,918	73,940	68,435	19,755	12,539	228,659	12
Reserve requirement (daily, millions)	351.98	266.25	265.26	76.57	21.09	854.93	12
Fulfillment (percent)	82.44	83.95	9.37	2.70	69.08	100.17	12
Norm gross excess reserves (percent)	-11.86	-11.60	12.04	3.47	-38.78	6.88	12
Norm net excess reserves (percent)	-217.10	-162.26	166.75	48.14	-596.13	-60.01	12
Write-offs and provisions (percent)	0.13	0.09	0.12	0.03	0.02	0.49	12
Return on assets (percent)	0.10	0.12	0.10	0.03	-0.15	0.24	12
Equity ratio (percent)	2.66	2.71	0.77	0.22	1.33	3.69	12

Panel F: Cooperative central banks

Assets (millions)	60,320	39,921	53,767	26,884	22,081	139,357	4
Reserve requirement (daily, millions)	241.17	113.85	277.29	138.64	80.54	656.42	4
Fulfillment (percent)	99.00	98.22	10.29	5.15	87.33	112.22	4
Norm gross excess reserves (percent)	6.76	-0.11	18.00	9.00	-6.10	33.36	4
Norm net excess reserves (percent)	-261.95	-157.97	268.94	134.47	-660.64	-71.21	4
Write-offs and provisions (percent)	0.24	0.18	0.15	0.08	0.13	0.46	4
Return on assets (percent)	0.20	0.16	0.18	0.09	0.05	0.44	4
Equity ratio (percent)	2.83	3.01	0.59	0.30	1.99	3.33	4

Table 2
Bank characteristics: nonbidders

Descriptive statistics on bank characteristic variables for four types of banks as classified by the Deutsche Bundesbank: private banks, savings banks, cooperatives, and branches of foreign banks. Nonbidders are all banks that did not participate in any main refinancing operation during the sample period (June 27, 2000 to December 18, 2001). There is no Landesbank or cooperative central bank nonbidder. All variables are as described in Table 1, but for nonbidders, there is no difference between gross and net excess reserves as there never is a maturing repo.

	Mean	Median	Standard deviation	Standard error	Minimum	Maximum	Observations
<i>Panel A: Private Banks</i>							
Assets (millions)	1,478	242	6,847	665	11	69,253	106
Reserve requirement (daily, millions)	6.99	1.71	16.73	1.62	0.01	131.21	106
Fulfillment (percent)	169.61	108.13	279.13	27.11	26.84	2,073.32	106
Norm net excess reserves (percent)	210.83	24.93	808.20	78.50	-141.97	5,584.70	106
Write-offs and provisions (percent)	0.73	0.31	1.03	0.10	0.00	5.37	106
Return on assets (percent)	0.89	0.25	1.97	0.19	-4.61	12.51	106
Equity ratio (percent)	13.80	8.58	13.35	1.30	1.35	67.42	106
<i>Panel b: Savings Banks</i>							
Assets (millions)	895	683	749	55	61	4,573	183
Reserve requirement (daily, millions)	10.10	7.60	8.59	0.63	0.61	43.16	183
Fulfillment (percent)	102.67	101.32	6.24	0.46	88.77	135.04	183
Norm net excess reserves (percent)	8.30	6.21	12.77	0.94	-10.25	129.95	183
Write-offs and provisions (percent)	0.43	0.39	0.25	0.02	0.00	1.28	183
Return on assets (percent)	0.24	0.22	0.15	0.01	0.02	1.35	183
Equity ratio (percent)	4.31	4.19	0.88	0.07	2.28	8.02	183
<i>Panel C: Cooperatives</i>							
Assets (millions)	234	148	302	8	12	4,220	1,275
Reserve requirement (daily, millions)	2.86	1.84	3.58	0.10	0.01	40.26	1,275
Fulfillment (percent)	105.93	101.06	79.51	2.23	74.53	2,476.16	1,275
Norm net excess reserves (percent)	25.33	5.98	325.48	9.12	-233.86	9,219.97	1,275
Write-offs and provisions (percent)	0.44	0.38	0.38	0.01	-0.24	5.35	1,275
Return on assets (percent)	0.21	0.22	0.29	0.01	-4.52	3.97	1,275
Equity ratio (percent)	5.28	5.11	1.20	0.03	1.82	19.75	1,275

Panel d: Foreign Banks

Assets (millions)	1,474	423	2,977	405	12	15,486	54
Reserve requirement (daily, millions)	9.61	2.06	27.29	3.71	0.00	191.84	54
Fulfillment (percent)	535.17	114.50	1,414.76	192.52	52.87	8,213.70	54
Norm net excess reserves (percent)	1,697.84	54.23	5,726.84	779.32	-15.89	35,075.25	54
Write-offs and provisions (percent)	0.20	0.06	0.27	0.04	0.00	0.91	54
Return on assets (percent)	0.88	0.27	1.65	0.22	0.03	6.72	54
Equity ratio (percent)	4.11	1.42	7.24	0.99	-1.05	35.42	54

Comparing these two tables reveals that the average bidder differs substantially on two key dimensions from the average nonbidder. First, category by category, bidders are larger than nonbidders by both asset size and reserve requirements. For example, for bidding private banks these measures average to (in euros) 22,794 million (asset size) and 132.43 million (average daily reserve requirement). The corresponding numbers for nonbidders are 1,478 million and 6.99 million.

Second, bidders are shorter liquidity than nonbidders. For bidders, the average normalized net excess reserves is negative for all bank categories; for nonbidders it is positive. So, by this measure, bidders are short going into the auctions, while nonbidders are long. For example, for private banks, the average normalized net excess reserves is -243.82%, with a median of -83.39%. For nonbidders, the mean and median are 210.83% and 24.93%, respectively. The average fulfillment is also smaller for bidders than it is for nonbidders. Thus, nonbidders are comparatively small and long, while bidders are comparatively large and short.

With respect to the financial health variables, things are less clear-cut. For all bank types, nonbidders have larger mean and median ROA than bidders. So, by this measure, nonbidders can be said to be financially more healthy. However, across the different bank types, there are both positive and negative differences between bidders and nonbidders with respect to mean and median write-offs and provisions. The same holds true for the equity ratio. For private banks that bid in at least one auction, the mean (median) write-offs and provisions, ROA, and equity ratio are 0.35% (0.21%), 0.34% (0.21%), and 4.96% (4.06%), respectively. The corresponding numbers for nonbidders are 0.73% (0.31%), 0.89% (0.25%), and 13.8% (8.58%).

The tables also show significant differences across bank categories. In Table 1 (bidders), Landesbanks and cooperative central banks are substantially larger than the other categories, including the private banks. Mean asset values are (in euros) 96,918 million for Landesbanks and 60,320 million for cooperative central banks, as compared with 22,794 million for private banks, 2,092 million for savings banks, 678 million for cooperatives, and

2,256 million for branches of foreign banks. So, on average by asset value, Landesbanks and cooperative central banks are up to 4.5 times larger than private banks. At the same time, private banks are approximately 10 times larger than savings and foreign banks, which in turn are approximately three times as large as cooperatives. The smallest asset value in the sample is 26 million (a cooperative), and the largest value is 267,591 million (a domestic private bank).

Differences also are apparent in liquidity status among bidding banks. For example, private domestic banks have a mean fulfillment of 100.25%. Savings banks and cooperatives have similar mean fulfillments, 102.65% and 102.94%, respectively. The mean fulfillment across foreign institutions is 142.30%. Landesbanks have the lowest fulfillment, 82.44%, and cooperative central banks have a fulfillment of 99.00%. So, on average, as measured by fulfillment, German private banks, savings banks, and cooperatives are slightly long, and cooperative central banks and, in particular, Landesbanks are short going into the auctions. However, taking into account maturing repos, all categories of banks are on average short going into the auctions, as seen by the negative mean and median normalized net excess reserves. There is substantial variation across individual banks. The normalized net excess reserves varies from $-3,739.82\%$ (a private bank) to 968.01% (a foreign bank).

3.3. Pricing and bidding measures and statistics

Table 3 reports on various pricing and bidding variables, by bank type. The table draws on all banks that bid at least once. For each bank, we measure the relevant variables first for each individual demand schedule (i.e., across the bidders' set of bids in a given auction). Then we average across demand schedules for each bank to obtain a population of bank-level observations, whose summary statistics are reported in the table.

To benchmark bids and rates paid in the main refinancing operations, we use the two-week Eonia swap rate taken as the midpoint of the bid and ask from Reuters quotations at 9:15 a.m. on the auction day. Our pricing variables are

Table 3
Pricing and bidding statistics for individual banks by type

Descriptive statistics on bidding and performance variables for six types of banks as classified by the Deutsche Bundesbank: private banks, savings banks, cooperatives, branches of foreign banks, Landesbanks, and cooperative central banks. The variables are defined in Subsection 3.3. Means of each variable are calculated first for each bidding bank. The reported statistics are then calculated across banks for each bank type. Sample period is from June 27, 2000 to December 18, 2001. bps: basis points.

	Mean	Standard deviation	Standard error	Minimum	Maximum	Observations
<i>Panel A: Private banks</i>						
Underpricing (bps)	1.24	1.75	0.19	-5.50	5.58	89
Relative underpricing (bps)	0.07	0.86	0.09	-3.47	1.65	89
Discount (bps)	3.04	2.07	0.21	-4.50	9.69	93
Relative discount (bps)	0.14	1.57	0.16	-4.89	5.92	93
Stop-out deviation (bps)	1.63	0.94	0.10	0.70	5.40	93
Award ratio (percent)	54.90	23.75	2.46	0.00	100.00	93
Award to total award (percent)	0.63	1.69	0.18	0.00	11.58	93
Bidding frequency (percent)	48.95	32.40	3.36	1.28	98.72	93
Number of bids	2.18	0.72	0.07	1.00	4.57	93
<i>Panel B: Savings banks</i>						
Underpricing (bps)	1.66	1.90	0.10	-5.75	9.25	352
Relative underpricing (bps)	-0.01	1.09	0.06	-7.71	3.46	352
Discount (bps)	3.32	2.81	0.15	-5.50	17.50	366
Relative discount (bps)	-0.09	1.76	0.09	-8.14	12.10	366
Stop-out deviation (bps)	1.73	1.28	0.07	0.00	11.00	366
Award ratio (percent)	57.41	23.62	1.23	0.00	100.00	366
Award to total award (percent)	0.09	0.17	0.01	0.00	1.97	366
Bidding frequency (percent)	44.43	32.47	1.70	1.28	100.00	366
Number of bids	2.29	0.88	0.05	1.00	5.13	366

Panel C: Cooperatives

Underpricing (bps)	0.78	2.55	0.15	-14.00	8.25	308
Relative underpricing (bps)	-0.87	1.80	0.10	-14.13	3.88	308
Discount (bps)	3.47	4.09	0.23	-14.00	31.25	324
Relative discount (bps)	-0.18	2.91	0.16	-14.24	21.37	324
Stop-out deviation (bps)	2.80	2.20	0.12	0.00	21.00	324
Award ratio (bps)	58.97	26.29	1.46	0.00	100.00	324
Award to total award (percent)	0.03	0.06	0.00	0.00	0.77	324
Bidding frequency (percent)	27.51	25.41	1.41	1.28	100.00	324
Number of bids	2.05	1.09	0.06	1.00	9.00	324

Panel D: Foreign banks

Underpricing (bps)	0.69	1.94	0.44	-4.75	3.29	19
Relative underpricing (bps)	-0.18	1.42	0.33	-5.71	1.02	19
Discount (bps)	2.84	4.24	0.93	-4.75	13.25	21
Relative discount (bps)	-0.15	2.35	0.51	-7.45	4.64	21
Stop-out deviation (bps)	1.94	1.57	0.34	0.40	7.00	21
Award ratio (percent)	58.34	28.36	6.19	0.00	100.00	21
Award to total award (percent)	0.17	0.32	0.07	0.00	1.15	21
Bidding frequency (percent)	34.68	27.90	6.09	1.28	97.44	21
Number of bids	1.87	0.84	0.18	1.00	4.22	21

Panel E: Landesbanks

Underpricing (bps)	1.48	1.14	0.33	-0.54	3.87	12
Relative underpricing (bps)	0.53	0.36	0.10	0.02	1.19	12
Discount (bps)	2.83	1.31	0.38	1.21	5.61	12
Relative discount (bps)	0.50	0.77	0.22	-0.51	2.31	12
Stop-out deviation (bps)	1.04	0.22	0.06	0.70	1.46	12
Award ratio (percent)	48.54	14.42	4.16	27.15	73.42	12
Award to total award (percent)	1.68	1.39	0.40	0.24	4.58	12
Bidding frequency (percent)	80.45	19.41	5.60	29.49	100.00	12
Number of bids	2.42	0.40	0.12	1.84	3.15	12

Panel F: Cooperative central banks

Underpricing (bps)	2.82	1.60	0.80	1.53	5.16	4
Relative underpricing (bps)	0.51	0.57	0.29	-0.15	1.24	4
Discount (bps)	4.27	2.23	1.12	2.38	7.50	4
Relative discount (bps)	0.45	0.61	0.30	-0.11	1.28	4
Stop-out deviation (bps)	1.17	0.31	0.15	0.83	1.55	4
Award ratio (percent)	42.34	16.93	8.46	18.34	56.57	4
Award to total award (percent)	1.45	0.90	0.45	0.53	2.64	4
Bidding frequency (percent)	49.36	31.97	15.98	3.85	75.64	4
Number of bids	3.51	1.49	0.74	2.43	5.67	4

Underpricing: a measure of the price paid by bidders relative to the contemporaneous swap rate. It equals the swap rate less the bidder's quantity-weighted average winning bids. We borrow from the IPO (initial public offerings) and auction literatures and call this spread underpricing because the rate paid is typically below the contemporaneous swap rate (midpoint of the bid and ask).

Relative underpricing: a bidder's underpricing in a given auction less the average underpricing in that auction across bidders (in the sample).

Discount: a measure of the willingness to pay. It equals the swap rate less the bidder's quantity-weighted average bid rate.¹⁴

Relative discount: a bidder's discount in a given auction less the average discount in that auction across bidders.

The price of liquidity can be said to be higher the lower is the underpricing or the relative underpricing. In addition to the pricing variables, we report on a number of bidding variables, which help provide a fuller picture of banks' bidding decisions.

Stop-out deviation: the quantity-weighted standard deviation of bids around the stop-out rate.¹⁵ This is a measure of how well a bank predicts the stop-out rate and, therefore, affects what it pays for liquidity. A small stop-out spread tends to result in a relatively large underpricing.

Award ratio: a bidder's award in an auction as a percentage of his demand.

Award to total award: a bidder's award in an auction as a percentage of aggregate award in that auction to financial institutions registered in Germany.

Bidding frequency: percentage of auctions a bank participates in.¹⁶

Number of bids: the number of interest rate–quantity pairs.

Substantial differences exist across bank categories in the prices paid for liquidity, as captured by underpricing and relative underpricing. Private banks have an average underpricing and relative underpricing of 1.24 bps and 0.07 bps, respectively. For savings

¹⁴We call this quantity discount because the rate bid is typically below the contemporaneous swap rate (midpoint of the bid and ask).

¹⁵The stop-out, or marginal, rate is the rate of the lowest winning bid.

¹⁶This means that, unlike the other variables, bidding frequency is not an average across a bank's demand schedules in different auctions.

banks, the corresponding numbers are 1.66 bps and -0.01 bps; for cooperatives, they are 0.78 bps and -0.87 bps; for foreign banks, they are 0.69 bps and -0.18 bps; for Landesbanks, they are 1.48 bps and 0.53 bps, and for cooperative central banks, they are 2.82 bps and 0.51 bps. Thus Landesbanks are the best performers, having a relative underpricing that is 1.40 bps higher than cooperatives, which are the worst performers. The Landesbanks are closely followed by the cooperative central banks.¹⁷

We see very similar results when we analyze the willingness to pay for liquidity across different bank categories, as captured by discount and relative discount. Private banks have an average discount and relative discount of 3.04 bps and 0.14 bps, respectively. For savings banks, the corresponding numbers are 3.32 bps and -0.09 bps; for cooperatives, they are 3.47 bps and -0.18 bps; for foreign banks, they are 2.84 bps and -0.15 bps; for Landesbanks, they are 2.83 bps and 0.50 bps; and for cooperative central banks, they are 4.27 bps and 0.45 bps. Thus Landesbanks and cooperative central banks, followed by the private banks, are willing to pay less for liquidity than the rest of the banks.

The stop-out deviation captures a banks' ability to correctly predict the stop-out rate in a given auction. It is lowest for the Landesbanks (1.04 bps) and cooperative central banks (1.17 bps) and highest for the cooperatives (2.80 bps). This could contribute to the larger relative underpricing we observe for the Landesbanks and cooperative central banks.

The award ratio measures the relative aggressiveness of a bidder. A ratio of 100% in a given auction means that all of a bidder's bids won, i.e., all his bids were above the stop-out rate. Thus, the bidder can be said to have been highly aggressive relative to other bidders. An award ratio of zero is indicative of very cautious bidding. Cooperative central banks have the lowest average award ratio, 42.34%, followed by the Landesbanks

¹⁷A caveat with respect to using the raw underpricing number, instead of the relative underpricing, to gauge what banks pay relative to each other is that the raw underpricing measure gives more weight to the early auctions in the sample period, because these auctions had a higher participation rate [see Nyborg, Bindseil and Strebulaev (2002) for a discussion of the decreasing time trend in the number of bidders]. Because interbank rates were higher around these auctions, the underpricing in these auctions was higher than in later auctions.

with 48.54%. Across the other bank categories, the range is from 54.90% for private banks to 58.97% for cooperatives.

The average award to total award varies from 0.03% (cooperatives), 0.09% (savings), 0.17% (foreign), 0.63% (private), 1.45% (cooperative central banks), and 1.68% (Landesbanks). The maximum is 11.58% (a private domestic bank). These numbers illustrate how small any bank in this market is compared with the market size.

Landesbanks participate more frequently than other banks. Specifically, they bid on average in 80.45% of the 78 auctions. Cooperative bidders participate in the fewest number of auctions, only 27.51%. As seen by comparing Tables 1 and 2, the cooperative sector also has the smallest participation rate, as measured by the percentage of banks in the sector that bid at least once. The average number of bids per demand schedule varies from 1.87 (foreign banks) to 3.51 (cooperative central banks).

4. Cross-sectional regressions

In this section, we take a preliminary look at the extent to which the bank characteristics discussed above affect the prices banks pay for liquidity by running cross-sectional regressions. This analysis is refined in Section 5, where we take advantage of the panel structure of the data, which allows us to incorporate into the analysis money market imbalance and banks' liquidity status at the time of each operation. The cross-sectional regressions in the current section are arguably most relevant for features that are permanent or relatively time invariant, such as bank type and size.

For each bidding bank, we consider the following dependent variables, as averages across the auctions in which the bank participated or won some units: underpricing, relative underpricing, discount, relative discount, stop-out deviation, and award ratio.¹⁸ As independent variables, we employ for each bank the natural log of the bank's assets, the net normalized excess reserves, write-offs and provisions, return on assets, and equity ratio, all as averages over the sample period. We also include bank sector dummy variables

¹⁸Underpricing and relative underpricing can be calculated only conditional on winning. The other dependent variables are calculated conditional on bidding.

for savings, cooperatives, foreign banks, Landesbanks, and cooperative central banks, thus taking private domestic banks as the benchmark. Finally, to examine whether small banks are especially sensitive to being short, for example due to being more vulnerable to predation along the lines of Carlin, Lobo, and Viswanathan (2007), we include an interaction variable, $small \times nex$, where $small$ is a dummy variable that takes one if the bank has average assets of less than 100 million euros over the sample period and zero otherwise. The expression nex is shorthand for the normalized net excess reserves. Standard errors are adjusted for heteroskedasticity by using the Huber-White estimate of variance.

Results are reported in Table 4. The price of liquidity decreases in bank size. The coefficient on $\ln(\text{assets})$ in the relative underpricing regression is 0.186 and is statistically significant at the 1% level. In other words, an increase in size (in millions) by a factor of e leads to a 0.186 bps increase in relative underpricing. In the (plain) underpricing regression, the coefficient is 0.149. The smaller underpricing of larger banks can be explained by two factors: (1) They bid at lower rates. The regression coefficient on $\ln(\text{assets})$ in the discount regression, for example, is -0.201 (significant at the 10% level). (2) Larger banks cluster their bids closer around the stop-out rate. The regression coefficient on $\ln(\text{size})$ in the stop-out deviation regression is -0.320 (significant at the 1% level). Thus, larger banks tend to win with lower bids than smaller banks. These results can also be seen from simple sorts on size. For example, the 5% and 6–10% smallest banks have an average underpricing of -1.33 bps and -0.39 bps; whereas banks in the 98th and 99th size percentiles have average underpricings of -0.80 bps and 0.76 bps.¹⁹

With respect to bank type, the most notable result is that cooperative banks have a lower relative underpricing than other banks. They pay a significant 0.395 bps more for liquidity than private banks.

¹⁹The average size of banks in these groups is 71.22, 130.6, 23,995.47, and 105,928.50 (in millions of euros) for the 0–5th, 6–10th, 98th, and 99th percentile, respectively. Details and further results on size-sorted groups are available in an earlier version of this paper.

Table 4
Cross-sectional regressions of pricing and bidding variables on bank characteristics

Each column represents a separate regression. Standard errors are adjusted for heteroskedasticity by using the Huber-White estimate of variance. t-statistics are in brackets. a, b, and c denote significance (two-tailed) at the 1%, 5%, and 10% level, respectively. Sample period is from June 27, 2000 to December 18, 2001. bps: basis points.

	Underpricing (bps)	Relative underpricing (bps)	Discount (bps)	Relative discount (bps)	Stop-out deviation (bps)	Award ratio (percent)
Constant	0.479 (0.63)	-1.477 ^a (-3.05)	6.064 ^a (5.52)	1.885 ^b (2.38)	4.642 ^a (8.58)	43.016 ^a (4.78)
ln(assets) [ln(mln)]	0.149 ^b (2.00)	0.186 ^a (3.84)	-0.201 ^c (-1.93)	-0.125 ^c (-1.66)	-0.320 ^a (-6.13)	0.381 (0.46)
Norm net excess reserves (percent)	4.4E-04 (1.43)	-1.7E-04 ^b (-2.02)	0.002 ^a (2.71)	0.001 ^b (2.09)	0.001 ^a (3.34)	-0.015 ^b (-2.39)
Small x nex (percent)	1.8E-05 (0.32)	-3.0E-05 (-0.71)	1.8E-05 (0.23)	-2.4E-05 (-0.43)	6.0E-05 ^b (2.44)	4.6E-05 (0.10)
Write-offs and provisions (percent)	1.841 (0.07)	2.250 (0.16)	39.643 (1.31)	23.692 (1.49)	-8.038 (-0.88)	-306.382 (-1.32)
Return on assets (percent)	-0.473 (-0.01)	27.874 (1.49)	-27.050 (-0.36)	-17.738 (-0.30)	-25.988 (-0.56)	-123.625 (-0.35)
Equity ratio (percent)	-0.067 ^c (-1.72)	-0.034 (-1.42)	-0.178 ^a (-2.63)	-0.114 ^a (-2.71)	0.001 (0.03)	1.237 ^b (2.45)
Savings bank	0.411 ^c (1.68)	0.169 (1.33)	-0.498 (-1.60)	-0.604 ^a (-2.60)	-0.456 ^a (-3.00)	6.742 ^b (2.10)
Cooperative bank	-0.240 (-0.76)	-0.395 ^b (-2.24)	-0.608 (-1.44)	-0.830 ^a (-2.65)	0.153 (0.73)	8.770 ^b (2.27)
Foreign bank	-0.181 (-0.37)	0.055 (0.27)	-0.240 (-0.21)	-0.391 (-0.68)	-0.275 (-0.69)	5.361 (0.66)
Landesbank	-0.405 (-1.02)	-0.056 (-0.32)	-0.157 (-0.31)	0.428 (1.24)	0.203 (1.08)	-4.651 (-0.92)
Cooperative central bank	1.043 (1.38)	-0.026 (-0.08)	1.284 (1.31)	0.357 (1.15)	0.251 (0.80)	-11.095 (-1.51)
Adjusted R^2	0.039	0.106	0.019	0.053	0.143	0.023
Observations	777	777	812	812	812	812

The regression coefficients on the normalized net excess reserves and the $\text{small} \times \text{nex}$ interaction variable suggest only a weak relation between a bank's typical liquidity position and the underpricing and discount variables. Moreover, for the normalized net excess reserves, the sign in one of the four pricing regressions is negative, not positive, as one would expect from a short squeezing line of argument. However, cross-sectional regressions are not the appropriate way to examine the effect of liquidity positions, because these change from auction to auction.

With the exception of the equity ratio, the financial health variables are statistically insignificant in all regressions. Surprisingly, an increase in the equity ratio is associated with a significantly higher willingness to pay for liquidity, as seen from its coefficients of -0.178 and -0.114 in the discount and relative discount regressions, respectively. The coefficients in the two underpricing regressions are negative, too, but only (marginally) significant in one of them. However, these regressions also ignore time variation in the equity ratio as well as operation-specific market conditions.

5. Panel regressions

In this section, we make full use of the panel structure of the data. We start by running plain panel regressions on the sample of bidding banks to test the hypotheses described in the Introduction. We are particularly interested in seeing whether an increase in money market imbalances leads to more aggressive bidding and whether this is especially so for banks that are smaller and have larger short positions. We examine the robustness of our findings by running Heckman selection regressions to take into account a bank's decision to participate in a given auction, using bidding as well as nonbidding banks.

5.1. *Imbalance and other explanatory variables*

We use our reserve position data to calculate a measure of imbalance in the market. In particular, for each operation, we define *imbalance* to be the standard deviation of the normalized net excess reserves across all banks, bidders and nonbidders alike. The

purpose of including this variable in our regressions is to examine the hypothesis that liquidity is more expensive when there is a greater imbalance in liquidity positions across banks. For each bank, we interact imbalance with the normalized net excess reserves (nex), to examine the extent to which more short banks could be more vulnerable to a greater imbalance in the market. Under the hypothesis that short squeezing is an issue, Nyborg and Strebulaev (2004) show that a more extreme dispersion of holdings across banks leads to more aggressive bidding by shorts that are subject to the possibility of being squeezed as well as by banks that have sufficient market power to implement a squeeze. Given the importance of bank size, shown in Section 4, we also interact imbalance with $\ln(\text{assets})$ to examine the extent to which smaller banks could have a further disadvantage in more imbalanced markets.

The full set of explanatory variables can be divided into five categories. First, we have the (more or less) permanent basic bank characteristics, $\ln(\text{assets})$ and bank type. Second, we have liquidity condition variables, which include a temporary bank characteristic, normalized net excess reserves; a market condition, imbalance; and three interaction variables, $\text{small} \times \text{nex}$, $\text{imbalance} \times \text{nex}$, and $\text{imbalance} \times \ln(\text{assets})$.²⁰ Third, we have the bank characteristics that relate to financial health; write-offs and provisions, return on assets, and equity ratio. Fourth, we have auction-specific market conditions; expected auction size and the size ratio. Fifth, we have interbank rate variables; the swap spread, the negative swap spread, and the conditional volatility of the two-week Eonia swap rate. The variables that are not already discussed above are

Size ratio: Under the hypothesis that positions matter and that short squeezing could be a concern, we would expect that the price of liquidity is larger when the operation offers a poor opportunity for refinancing maturing loans from the operations two weeks ago. To examine this, we define the size ratio to be the expected size of the current operation as a percentage of the size of the operation two weeks ago and which now needs to be refinanced.

Interbank rate variables: These are included as control variables.²¹ *Swap spread* is the

²⁰Nex is the normalized net excess reserves.

²¹Nyborg, Bindseil and Strebulaev (2002), who first examined their impact, find they were significant

two-week Eonia swap rate at 9:15 a.m. on operation days less the minimum bid rate in the auction. Because bidders cannot submit bids below the minimum bid rate, the swap spread puts an upper bound on a bidder's underpricing and discount. The *conditional volatility* of the two-week Eonia swap rate on operation days is calculated using a modified GARCH(1,1) model (Bollerslev, 1986), based on daily observations at 9:15 a.m. in the period January 4, 1999 to December 20, 2001.²² The *negative swap spread* is a dummy variable that is one if the swap rate is below the minimum bid rate and zero otherwise.

Summary statistics for the market condition variables, including the two market condition interaction variables, are in Table 5. Imbalance has a mean of 1,144% and a standard deviation of 3,331%. It is highly skewed. The minimum is 86%, the median is 400%, and the maximum is 26,997%. $\text{Imbalance} \times \text{nex}$ has a mean of -208,065%² and a standard deviation of approximately (minus) 13 times that. $\text{Imbalance} \times \ln(\text{assets})$ has a mean of 7,543 and a standard deviation of around three times that. The size ratio averages to 1.24 and has a standard deviation of 1.75. Its minimum is 0.2 and its maximum is 15.8, illustrating that there is a substantial range in this measure. There is substantially larger scope to refinance a repo when the current auction is 15.8 times larger than the previous one as compared with when the size ratio is merely 0.2. The expected auction size has an average of 84.26 billion euros, with a standard deviation of 28.83 billion. On auction days, the swap spread has an average of 5.91 bps, with a standard deviation of 8.66 bps. The volatility of the swap rate has an average of 5.32 bps on auction days, with a standard deviation of 1.33 bps.

and that the swap spread in particular contributes to a high R^2 . Our findings with respect to these variables are similar.

²²We have considered various calendar effects, as in Hamilton (1996). The final specification is along the lines of that in Nyborg, Bindseil and Strebulaev (2002). For details, contact us or see earlier working paper versions of this paper.

Table 5
Market condition and interaction variables

Listed are descriptive statistics of market condition and interaction explanatory variables. Imbalance is the standard deviation of the normalized net excess reserves across all banks before a given auction. $\text{Imbalance} \times \text{nex}$ and $\text{Imbalance} \times \ln(\text{assets})$ are interaction variables for which imbalance is multiplied by the normalized net excess reserves and log of assets, respectively, for each bidder in a given auction. (Nex denotes normalized net excess reserves.) Size ratio is the ratio of the expected auction size in auction j and the realized auction size in auction $j - 2$. Expected auction size is the liquidity neutral amount, which is computed from the liquidity figures announced by the European Central Bank the afternoon on the day prior to the auction. Swap spread is the difference between the two-week Eonia swap rate and the minimum bid rate at 9:15 a.m. on the auction day. Volatility of swap rate is the conditional volatility of the two week Eonia swap rate on auction days (see footnote 22). Sample period is from June 27, 2000 to December 18, 2001.

	Mean	Median	Standard deviation	Standard error	Minimum	Maximum	Observations
Imbalance (percent)	1,144	400	3,331	382	86	26,997	76
$\text{Imbalance} \times \text{nex}$ (percent \times percent)	-208,065	-42,118	2,770,774	18,022	-9.79E+07	3.67E+08	23,635
$\text{Imbalance} \times \ln(\text{assets})$ [percent $\times \ln(\text{mln})$]	7,543	2,945	21,128	137	282	339,127	23,673
Size ratio (100%)	1.24	0.98	1.75	0.20	0.20	15.80	76
Expected auction size (billions)	84.26	83.00	28.83	3.26	5	177	78
Swap spread (basis points)	5.91	4.25	8.66	0.98	-9.00	48.25	78
Volatility of swap rate (basis points)	5.32	5.78	1.33	0.15	0.19	9.30	78

5.2. Plain panel regressions

In this subsection, we run panel regressions of underpricing, relative underpricing, discount, relative discount, stop-out deviation, and award ratio on the explanatory variables discussed above. The liquidity status, auction-specific market conditions, and interbank rate variables are available for each individual operation. $\ln(\text{assets})$ and the equity ratio are available monthly. In the regressions, for each operation we use the values of these two variables at the end of the month prior to the start of the maintenance period that the operation falls under. Write-offs and provisions and return on assets are measured at the end of the year before the respective operation. To allow for variations in conditions in different maintenance periods, the regressions are run with maintenance period fixed effects. Standard errors are adjusted for heteroskedasticity by using the Huber-White estimate of variance and are clustered on the auctions.²³

Table 6 reports the results. Each column represents a different regression, and we discuss each in turn. The underpricing regression confirms our earlier results that large banks pay less for liquidity. The coefficient on $\ln(\text{size})$ in the underpricing regression is a statistically significant (at the 1% level) 0.174.

With respect to the liquidity status variables, the coefficient on the normalized net excess reserves is statistically insignificant in both the underpricing and relative underpricing regressions. However, when we separate out small banks, we do get a significant effect. In both cases, the coefficient on $\text{small} \times \text{nex}$ is significantly positive, albeit small. Thus, for small banks, the shorter their positions, the lower is their underpricing; i.e., the higher is the price they pay for liquidity. It appears that it is especially small banks that suffer from being short.

The results relating to the distribution of liquidity positions across banks are stronger. The coefficients on imbalance in the underpricing regressions are negative and statistically significant, meaning that the price of liquidity in repos with the central bank relative to the

²³Running panel estimations with standard errors clustered on banks, we obtain similar results.

Table 6

Panel regressions of pricing and bidding variables on market conditions and bank characteristics

Each column represents a separate regression, all run with maintenance period fixed effects. Standard errors are clustered on each auction and adjusted for heteroskedasticity by using the Huber-White estimate of variance. t-statistics are in brackets. a, b, and c denote significance (two-tailed) at the 1%, 5%, and 10% level, respectively. Nex denotes normalized net excess reserves. Control variables whose coefficients are not reported are: swap spread, negative swap spread, and the conditional volatility of the Eonia swap. Sample period is from June 27, 2000 to December 18, 2001. bps: basis points.

	Underpricing (bps)	Relative underpricing (bps)	Discount (bps)	Relative discount (bps)	Stop-out deviation (bps)	Award ratio (percent)
Constant	-0.292 (-0.28)	-1.259 ^a (-4.51)	1.774 (1.57)	-1.021 ^c (-1.91)	1.110 ^b (2.45)	23.654 ^b (2.56)
ln(assets) [ln(mln)]	0.174 ^a (10.34)	0.162 ^a (9.12)	0.029 (0.71)	0.017 (0.40)	-0.191 ^a (-7.61)	-0.241 (-0.73)
Norm net excess reserves (percent)	-3.8E-05 (-0.85)	1.9E-06 (0.06)	2.3E-04 ^a (3.65)	2.3E-04 ^a (4.19)	8.9E-05 ^b (2.59)	-0.006 ^a (-6.70)
Small × nex (percent)	1.9E-05 ^a (3.41)	1.8E-05 ^a (3.16)	2.2E-05 ^a (2.82)	2.2E-05 ^a (2.82)	-7.9E-06 ^c (-1.82)	-2.8E-05 (-0.34)
Write-offs and provisions (percent)	-17.258 ^a (-3.44)	-16.817 ^a (-3.80)	-6.611 (-0.94)	-6.642 (-0.96)	16.859 ^a (3.78)	227.456 ^a (3.22)
Return on assets (percent)	6.228 (1.62)	8.335 ^b (2.29)	17.402 ^a (2.75)	17.625 ^a (2.83)	4.487 (1.29)	-59.745 (-0.84)
Equity ratio (percent)	0.025 ^a (3.63)	0.020 ^a (2.82)	-0.014 (-1.15)	-0.020 (-1.54)	-0.021 ^a (-2.76)	0.590 ^a (3.91)
Imbalance (percent)	-9.8E-06 ^a (-6.28)	-5.6E-06 ^a (-6.40)	-1.5E-05 ^a (-6.85)	-9.4E-06 ^a (-5.57)	4.7E-06 ^a (3.83)	1.3E-04 ^a (3.03)
Imbalance × nex (percent × percent)	7.3E-10 ^a (3.62)	5.4E-10 ^a (4.09)	-3.9E-10 (-1.39)	-4.4E-10 ^c (-1.81)	-8.2E-10 ^a (-5.31)	1.3E-08 ^a (2.91)
Imbalance × ln(assets) [percent × ln(mln)]	4.2E-07 ^a (3.22)	5.1E-07 ^a (4.43)	9.5E-07 ^a (4.06)	1.0E-06 ^a (4.76)	-2.0E-07 (-1.33)	-6.7E-08 ^b (-2.60)
Size ratio (100%)	0.098 ^b (2.23)	-0.021 ^b (-2.32)	0.069 (1.48)	0.015 (0.92)	-0.039 ^b (-2.03)	-0.026 (-0.08)
Exp. auction size (billions)	0.022 ^a (3.95)	-0.001 (-0.44)	0.016 ^b (2.38)	0.004 (1.12)	0.004 (1.43)	0.253 ^a (3.67)
Savings bank	0.034 (0.54)	0.019 (0.34)	-0.458 ^a (-4.29)	-0.463 ^a (-4.38)	-0.229 ^a (-3.02)	9.070 ^a (8.17)
Cooperative bank	-0.415 ^a (-7.08)	-0.407 ^a (-7.68)	-0.477 ^a (-7.68)	-0.460 ^a (-5.59)	0.167 ^a (3.24)	6.541 ^a (5.58)
Foreign bank	-0.141 (-1.41)	-0.121 (-1.44)	-0.721 ^a (-5.46)	-0.693 ^a (-5.43)	-0.061 (-0.64)	13.537 ^a (6.23)
Landesbank	-0.012 (-0.19)	-0.071 (-1.27)	0.189 (1.13)	0.220 (1.29)	0.249 ^a (3.48)	-4.289 ^a (-2.86)
Cooperative central bank	-0.153 (-1.30)	-0.141 (-1.47)	0.028 (0.16)	0.047 (0.28)	0.217 ^b (2.55)	-4.989 ^c (-1.77)
Adjusted R ²	0.605	0.067	0.571	0.044	0.227	0.226
Observations	19,088	19,088	23,461	23,461	23,461	23,461

contemporaneous swap rate increases when there is greater imbalance in liquidity positions across banks. The effect is small, but so are the magnitudes we are dealing with in this market. A one standard deviation increase in imbalance leads to a decrease in underpricing of approximately 0.033 bps. The coefficient on the interaction variable $\text{imbalance} \times \text{nex}$ is positive and statistically significant. A one standard deviation increase in this variable has a 0.002 bps effect on underpricing. Thus, as imbalance increases, banks pay more for liquidity the shorter their positions are. The interaction variable $\text{imbalance} \times \ln(\text{assets})$ is also positive and statistically significant. In this case, a one standard deviation increase in the independent variable leads to an increase in underpricing of approximately 0.01 bps. In other words, as imbalance increases, large banks suffer less than small banks, in terms of the price they pay for liquidity. This is further support for the view that small banks are more vulnerable to tightness in the interbank market.

Turning now to the operation-specific market condition variables, the coefficients on the size ratio and the expected size are 0.098 and 0.022, respectively, both significant at the 1% level. So, as the auction size grows, the price paid for liquidity falls. The positive coefficient on expected size could reflect that increasingly expensive collateral has to be used as the auction size grows. The positive size ratio coefficient reveals that the price of liquidity gets relatively more expensive when the scope for refinancing falls. This illustrates that aggregate positions matter.

Worse financial health is associated with an increase in the price of liquidity. A 1 percentage point worsening in write-offs and provisions, the equity ratio, and the return on assets leads to a decrease in underpricing of 17.258 bps, 0.025 bps, and 6.228 bps, respectively. The coefficient on write-offs and provisions is large, especially given an average underpricing of 0.74–1.94 bps and a standard deviation of write-offs and provisions of 0.12%–0.60% depending on bank type.

Looking at the bank type dummies, we see that only the cooperatives have an underpricing that is statistically different from that of private banks. So the univariate results that Landesbanks and cooperative head institutions pay less do not survive the multivariate analysis. Controlling for all other factors, cooperatives pay 0.415 bps more for liquidity than private banks.

The relative underpricing regression is similar, except that most of the market condition variables have lost or reduced statistical and economic significance, as one would expect. The coefficient on imbalance and the two interaction variables are still statistically significant. The negative coefficient on imbalance means that the distribution of the price paid for liquidity across banks in an operation is skewed toward higher rates. This is consistent with the view that a larger imbalance leads to a larger chance of a liquidity squeeze.

The discount and relative discount regressions are also in line with the underpricing regression, but with some notable exceptions. First, paralleling the cross-sectional regressions, $\ln(\text{assets})$ is not significantly different from zero. Second, the normalized net excess reserves is now significant at the 1% level. Specifically, in the plain discount regression the coefficient is 2.3×10^{-4} , showing that the shorter a bank is the smaller is the discount. This is equivalent to saying that a one standard deviation (for private banks) decrease in the normalized net excess reserve leads to an increase in the relative discount by approximately 0.1 bps. Savings banks and branches of foreign banks have a lower discount, and thus a higher willingness to pay, than private banks, yet they do not end up paying more. A part of the explanation for this, at least for savings banks, is that they have a significantly lower stop-out deviation.

The stop-out deviation measures how close to the stop-out rate banks submit their bids. A low stop-out deviation tends to reduce the price paid for liquidity. A consistently low stop-out deviation could be the result of ability or an informational advantage with respect to where the market is. It could also arise for banks that are not concerned with being squeezed or rationed in the interbank market, because such banks need not be so aggressive in the auctions as banks that are concerned with these issues. Large banks could have a lower stop-out deviation for both of these reasons. Our results also show that banks with large write-offs and provisions or small equity ratios have larger stop-out deviations. Coupled with the fact that write-offs and provisions do not affect discounts, this suggests that less financially healthy banks use a strategy in which they try to counteract high bids, placed to ensure success in the auction, with low bids, to try to reduce the overall price paid. The end result is that they pay more. We also see that small short banks have

larger stop-out deviations, but these banks also have smaller discounts.

The award ratio regression shows that this variable tends to increase in write-offs and provisions, which is in line with the results that financially unhealthy banks are more desperate to obtain funds from the central bank. An alternative but not wholly unrelated interpretation is that these banks bid more aggressively because they are in possession of collateral of especially low quality. Banks with larger short positions also bid more aggressively, as measured by the award ratio. Again, this is in line with our other findings.

To summarize, the panel regressions show that liquidity positions affect the price paid for liquidity and bid levels. But it is not just a bank's own position that matters; it is especially how liquidity is distributed across banks. The more imbalance there is, the more are banks willing to pay and the more do they end up paying, especially the shorter and smaller they are.²⁴ Our results also show that financial health is important. Less healthy banks bid more aggressively and pay more for liquidity than more healthy banks. The panel analysis also confirms the finding from the cross-sectional regressions that banks pay more for liquidity the smaller they are.

5.3. Panel regressions with Heckman correction

The estimation methodology in Subsection 5.2 does not consider a bank's decision to participate in an auction or not. If this decision is nonrandom, the estimated coefficients would be inconsistent. In this subsection, we correct for the possibility of a selection bias by using a Heckman selection model. This model combines a selection mechanism for participating in the main refinancing operation with a regression model.

²⁴While the evidence is thus consistent with short squeezing being a concern, from a theoretical perspective one could also contemplate the possibility that banks with excess liquidity could be squeezed, because their alternative to trading in the market would be to use the deposit facility, which is 100 bp below the minimum bid rate in the auctions. Reasons that it could be worse being short than long include that a short bank needs eligible collateral to access the marginal lending facility and that, given the ECB's liquidity neutral policy, if some liquidity is taken out of the interbank market through inefficient liquidity management at the individual bank level (e.g., due to a bank with a small amount of excess liquidity not participating in the interbank market), the ECB's liquidity neutral policy gives rise to a shortage of liquidity in the interbank market.

Indexing banks by i and operations by j , the selection equation is

$$z_{ij}^* = \gamma' w_{ij} + \mu_{ij}. \quad (6)$$

The regression model is

$$y_{ij} = \beta' x_{ij} + \epsilon_{ij}, \quad (7)$$

where $(\mu_{ij}, \epsilon_{ij})$ are assumed to be bivariate normal $[0, 0, 1, \sigma_\epsilon, \rho]$.

z_{ij}^* is not observed; the variable is observed as $z_{ij} = 1$ if $z_{ij}^* > 0$ and zero otherwise with probabilities $\text{Prob}(z_{ij} = 1) = \Phi(\gamma' w_{ij})$ and $\text{Prob}(z_{ij} = 0) = 1 - \Phi(\gamma' w_{ij})$. $z_i = 1$ indicates that the bank participates and Φ is the standardized normal cumulative distribution function.

In the selected sample,

$$E[y_{ij}|z_{ij} = 1] = \beta' x_{ij} + \rho\sigma_\epsilon\lambda(\gamma' w_{ij}), \quad (8)$$

where λ is the inverse Mills ratio.

The model is estimated by maximum likelihood, which provides consistent, asymptotically efficient parameter estimates (see Greene, 2000). Standard errors are adjusted for heteroskedasticity by using the Huber-White estimate of variance and are clustered at the auction level.

The set of explanatory variables, x , in the regression model is the same as in the panel regressions in subsection 5.2.²⁵ In the selection equation, we use two additional variables, namely, *maturing repo indicator* and *last auction*. The maturing repo indicator is one if the bank won some units two operations ago, and last auction is the aggregate underpricing in the previous main refinancing operation. We expect that a bank is more likely to participate if it has to refinance (the maturing repo indicator is one). The results are virtually the same with or without the variable last auction.

The Heckman model is run on the full data set, including bidding banks and nonbidding banks. Results are in Table 7. Panel A presents the regression model; Panel B the selection model; and Panel C statistics on the parameters.

²⁵However, we now do not include maintenance period fixed effects.

Table 7

Heckman sample selection panel regressions of pricing and bidding variables on market conditions and bank characteristics

Each column represents a separate regression. Standard errors are clustered on each auction and adjusted for heteroskedasticity by using the Huber-White estimate of variance. t-statistics are in brackets. a, b, and c denote significance (two-tailed) at the 1%, 5%, and 10% level, respectively. Nex denotes normalized net excess reserves. The selection equation (Panel B) is run on the full sample of bidding and nonbidding banks. Control variables whose coefficients are not reported are: swap spread, negative swap spread, and the conditional volatility of the Eonia swap. Sample period is from June 27, 2000 to December 18, 2001. In Panel C standard errors are in italics. bps: basis points.

	Underpricing (bps)	Relative underpricing (bps)	Discount (bps)	Relative discount (bps)	Stop-out deviation (bps)	Award ratio (percent)
<i>Panel A: Bidding and Performance</i>						
Constant	-1.530 (-1.25)	-1.575 ^a (-5.08)	0.216 (0.16)	-1.461 ^b (-2.35)	1.220 ^b (2.29)	51.053 ^a (3.84)
ln(assets) [ln(mln)]	0.131 ^a (4.67)	0.180 ^a (9.78)	0.055 (1.03)	0.089 ^b (2.03)	-0.167 ^a (-6.95)	-1.691 ^a (-4.20)
Norm net excess reserves (percent)	-3.1E-05 (-0.77)	-2.6E-05 (-1.01)	1.4E-04 ^b (2.53)	1.4E-04 ^a (2.98)	4.0E-05 (1.57)	-0.003 ^a (-4.63)
Small × nex (percent)	1.8E-05 ^a (2.58)	1.6E-05 ^a (2.75)	1.5E-05 ^c (1.79)	1.3E-05 ^c (1.77)	-1.1E-05 ^b (-2.48)	1.3E-04 (1.55)
Write-offs and provisions (percent)	-36.261 ^a (-3.40)	-13.612 ^a (-3.07)	-13.088 (-1.11)	1.826 (0.22)	16.329 ^b (2.37)	20.880 (0.17)
Return on assets (percent)	7.373 (1.63)	8.399 ^b (2.28)	18.599 ^a (2.76)	17.700 ^a (2.71)	4.680 (1.37)	-64.452 (-0.91)
Equity ratio (percent)	0.011 (1.15)	0.022 ^a (3.23)	-0.028 ^b (-2.38)	-0.016 (-1.27)	-0.020 ^a (-2.65)	0.581 ^a (4.00)
Imbalance (percent)	-1.0E-05 ^a (-4.54)	-5.1E-06 ^a (-5.72)	-1.3E-05 ^a (-5.03)	-8.0E-06 ^a (-4.42)	4.3E-06 ^a (3.27)	6.1E-05 ^b (2.55)
Imbalance × nex (percent × percent)	7.3E-10 ^a (3.60)	6.3E-10 ^a (5.83)	-1.1E-10 (-0.41)	-1.2E-10 (-0.61)	-6.4E-10 ^a (-5.32)	5.3E-09 (1.32)
Imbalance × ln(assets) [percent × ln(mln)]	5.5E-07 ^a (4.02)	4.9E-07 ^a (4.60)	9.6E-07 ^a (3.83)	9.4E-07 ^a (4.41)	-2.4E-07 ^c (-1.69)	-5.2E-06 ^b (-2.24)
Size ratio (100%)	0.104 ^a (4.54)	-0.008 (-1.47)	0.094 ^a (3.19)	0.004 (0.21)	-0.031 ^a (-2.62)	-0.498 ^b (-2.08)
Expected auction size (billions)	0.030 ^a (3.63)	-0.001 (-0.45)	0.018 ^b (2.02)	0.003 (1.01)	0.006 ^c (1.82)	0.332 ^a (3.85)
Savings bank	0.021 (0.33)	0.051 (0.93)	-0.375 ^a (-3.15)	-0.354 ^a (-3.30)	-0.177 ^b (-2.33)	6.717 ^a (5.60)
Cooperative bank	-0.365 ^a (-5.67)	-0.408 ^a (-7.59)	-0.465 ^a (-4.75)	-0.480 ^a (-5.39)	0.167 ^a (-0.39)	6.731 ^a (5.39)
Foreign bank	-0.144 (-1.20)	-0.088 (-1.05)	-0.577 ^a (-4.06)	-0.587 ^a (-4.72)	-0.039 (-0.39)	11.092 ^a (5.21)
Landesbank	-0.019 (-0.27)	-0.068 (-1.19)	0.166 (1.05)	0.228 (1.37)	0.248 ^a (3.48)	-4.392 ^a (-2.97)
Cooperative central bank	-0.021 (-0.14)	-0.183 ^b (-1.96)	0.096 (0.52)	-0.077 (-0.47)	0.194 ^b (2.23)	-3.370 (-1.20)
N uncensored	19,088	19,088	23,461	23,461	23,461	23,461

Panel B: Selection

Constant	-3.779 ^a (-28.62) 0.244 ^a (25.82)	-3.778 ^a (-28.44) 0.244 ^a (25.77)	-3.525 ^a (-31.68) 0.264 ^a (28.53)	-3.529 ^a (-31.20) 0.264 ^a (28.30)	-3.525 ^a (-31.81) 0.265 ^a (28.64)	-3.528 ^a (-31.44) 0.263 ^a (28.49)
Norm net excess reserves (percent)	-1.4E-06 (-0.19)	-1.4E-06 (-0.19)	-8.6E-07 (-0.12)	-8.5E-07 (-0.12)	-8.6E-07 (-0.12)	-8.9E-07 (-0.13)
Small × nex (percent)	-1.6E-05 ^a (-6.17)	-1.6E-05 ^a (-6.14)	-1.8E-05 ^a (-6.68)	-1.8E-05 ^a (-6.65)	-1.7E-05 ^a (-6.67)	-1.8E-05 ^a (-6.64)
Write-offs and provisions (percent)	-3.767 ^a (-2.79)	-3.733 ^a (-2.79)	-3.125 ^a (-2.88)	-3.006 ^a (-2.79)	-3.160 ^a (-2.89)	-2.957 ^a (-2.74)
Return on assets (percent)	-8.221 ^a (-6.24)	-8.219 ^a (-6.22)	-7.762 ^a (-6.94)	-7.748 ^a (-6.94)	-7.780 ^a (-7.01)	-7.708 ^a (-6.87)
Equity ratio (percent)	0.006 ^a (2.68)	0.006 ^a (2.67)	0.003 (1.45)	0.003 (1.44)	0.003 (1.47)	0.003 (1.47)
Imbalance (percent)	1.6E-06 ^a (2.93)	1.6E-06 ^a (2.92)	2.0E-06 ^a (3.24)	2.0E-06 ^a (3.25)	2.0E-06 ^a (3.22)	1.9E-06 ^a (3.28)
Imbalance × nex (percent × percent)	9.6E-11 (0.55)	9.7E-11 (0.56)	8.7E-11 (0.48)	8.7E-11 (0.48)	8.6E-11 (0.47)	9.1E-11 (0.51)
Imbalance × ln(assets) [percent × ln(mln)]	-6.0E-08 (-0.87)	-5.9E-08 (-0.85)	-1.5E-07 ^c (-1.79)	-1.4E-07 ^c (-1.77)	-1.5E-07 ^c (-1.80)	-1.4E-07 ^c (-1.77)
Size ratio (100%)	0.018 ^a (5.89)	0.018 ^a (5.92)	0.019 ^a (6.80)	0.020 ^a (6.82)	0.019 ^a (6.74)	0.019 ^a (6.78)
Expected auction size (billions)	0.002 ^a (2.88)	0.002 ^a (2.86)	0.002 ^a (2.86)	-3.0E-05 (-0.04)	-7.4E-05 (-0.09)	-2.9E-05 (-0.04)
Savings bank	0.207 ^a (7.09)	0.208 ^a (7.09)	0.166 ^a (6.92)	0.166 ^a (6.89)	0.165 ^a (6.84)	0.166 ^a (6.91)
Cooperative bank	-0.091 ^a (-3.24)	-0.091 ^a (-3.24)	-0.117 ^a (-4.88)	-0.117 ^a (-4.87)	-0.117 ^a (-4.85)	-0.117 ^a (-4.84)
Foreign bank	0.062 (1.14)	0.062 (1.16)	0.062 (1.16)	-0.022 (-0.43)	-0.022 (-0.43)	-0.020 (-0.39)
Landesbank	0.062 (0.77)	0.063 (0.78)	0.156 ^b (1.96)	0.153 ^c (1.93)	0.156 ^c (1.95)	0.143 ^c (1.82)
Cooperative central bank	-0.165 (-1.21)	-0.164 (-1.20)	-0.085 (-0.67)	-0.087 (-0.69)	-0.087 (-0.69)	-0.094 (-0.74)
Maturing repo indicator	2.431 ^a (58.41)	2.431 ^a (58.36)	2.352 ^a (60.20)	2.351 ^a (60.01)	2.351 ^a (60.28)	2.351 ^a (59.55)
Last auction	2.439 ^a (2.86)	2.491 ^a (2.90)	1.807 ^b (2.23)	1.940 ^b (2.41)	1.722 ^b (2.17)	1.999 ^a (2.66)
Observations	164,746	164,746	169,119	169,119	169,119	169,119

Panel C: Parameters

Log pseudolikelihood	-69721	-63710	-93279	-89687	-79036	-149881
Prob>chi2	0.372	0.021	0.027	0.000	0.002	0.000
rho	-0.034	0.049 ^b	0.083 ^b	0.129 ^b	0.071 ^b	-0.219 ^b
	<i>0.038</i>	<i>0.021</i>	<i>0.037</i>	<i>0.030</i>	<i>0.023</i>	<i>0.031</i>
sigma	2.352 ^b	1.717 ^b	3.235 ^b	2.784 ^b	1.762 ^b	36.490 ^b
	<i>0.138</i>	<i>0.139</i>	<i>0.321</i>	<i>0.302</i>	<i>0.155</i>	<i>0.965</i>
lambda	-0.080	0.085 ^b	0.268 ^b	0.360 ^b	0.125 ^b	-7.975 ^b
	<i>0.091</i>	<i>0.037</i>	<i>0.110</i>	<i>0.066</i>	<i>0.043</i>	<i>1.108</i>

Comparing Panel A with the plain panel regression in Table 6, a few notable differences are apparent. For the most part, the variables that were significant remain so, though sometimes with altered p -levels, and the coefficients are very close to what they were before. Few variables go from being insignificant to significant. The most notable exceptions are as follows. First, $\ln(\text{assets})$ goes from being insignificant in the plain panel relative underpricing and award ratios regressions to being significantly positive and negative, respectively. So larger banks bid at lower rates than smaller banks and are less aggressive overall. This supports our other findings. Second, larger write-offs and provisions do not lead to significantly larger award ratios after all. Third, $\text{imbalance} \times \text{nex}$ is not significant in the relative discount regression.²⁶ However, its coefficient is still significantly positive in the two underpricing regressions. In sum, overall, the conclusions from the previous section remain intact.

In Panel B the selection equation is very similar for the different independent variables. This illustrates its robustness. Increased bank size is associated with a larger likelihood to participate, as is being a savings bank. Cooperatives and foreign banks are less likely to participate. With respect to liquidity status, a larger imbalance is associated with a larger participation rate, consistent with the interpretation that this variable is associated with squeezes. The more likely a squeeze is, the more important it is to participate to cover one's short position, or possibly being able to squeeze. An increase in return on assets is associated with a decrease in the likelihood of bidding, perhaps because banks that are generating larger earnings have less need to obtain liquidity from others. Loss of financial health as measured by an increase in write-offs and provisions is surprisingly associated with a fall in the probability of participating. This could reflect a lack of collateral. A bank is more likely to participate when the size ratio is large. This is not surprising, because a larger relative auction size is indicative of an increased need for liquidity in the banking system. An increase in expected auction size is associated with an increased likelihood of bidding. The positive coefficients on the maturing repo indicator and last auction confirm that banks are more likely to participate if they have a refinancing need and also when

²⁶The size ratio also behaves slightly differently with the Heckman correction.

the previous auction was highly underpriced.

Panel C reports the different parameters for the Heckman estimation, i.e., ρ , σ , and λ . The results suggest that these parameters are significant for each estimation except for underpricing. In particular, the correlation of the residuals in the bidding and performance model and the selection model, which is captured by ρ , is significant at the 5% level. This suggests that it is important to use the Heckman approach to take into account the decision whether to submit a bid for the analysis of how bidders submit their bids. Nevertheless, the results from the Heckman panel regression are very similar as in the plain panel regression.

5.4. Liquidity networks and government guarantees

This subsection differentiates between the effects of liquidity networks and government guarantees by focusing on differences in underpricing between cooperatives (which are part of formal liquidity networks but have no government guarantees) and savings banks (which are part of formal liquidity networks and had government guarantees during the sample period). Tables 6 and 7 show that, *ceteris paribus*, the underpricing of savings banks is the same as for private banks, while that of cooperatives is a statistically significant 0.4 bps lower. In other words, institutions that are part of formal liquidity networks pay more than private banks (which are not), unless they also have government guarantees, in which case they pay the same. This gives rise to the notion that these formal networks could induce banks to free-ride on the efforts of other banks in the network, along the lines of Bhattacharya and Gale (1987). An alternative view is that cooperatives and savings banks that participate in the main refinancing operations do so because they experience rationing within their respective networks. This could carry stigma, leading them to have to pay more for liquidity in the market. In either case, the conclusion appears to be that the networks do not function well for all members.

The government guarantees of savings banks should reduce credit risk associated with lending to these institutions, and thus their superior performance as compared with cooperatives is not surprising. However, in theory these guarantees should not offer protection from short squeezing, because this is fundamentally about market power, not

credit risk. To test this and investigate in more detail the incremental benefits of government guarantees, we rerun our Heckman panel regressions with five additional explanatory variables, namely, each of the five bank-group dummies interacted with imbalance. The coefficients and z -statistics (in brackets) of these five new variables in the underpricing regression are: $\text{imbalance} \times \text{savings}$, $-3.7\text{E-}06$ (-11.02); $\text{imbalance} \times \text{cooperatives}$, $-2.6\text{E-}06$ (-6.42); $\text{imbalance} \times \text{foreign}$, $-3.2\text{E-}07$ (-0.51); $\text{imbalance} \times \text{Landesbanks}$, $-2.7\text{E-}06$ (-4.88); and $\text{imbalance} \times \text{cooperative central banks}$, $-1.1\text{E-}04$ (-1.82).²⁷

The statistically significant negative coefficients show that both savings banks and cooperatives react more strongly to increased imbalance than do private banks (which constitute the benchmark group in the regression), as do their head institutions. Thus, while savings banks typically pay the same as private banks with similar characteristics, savings banks do worse as imbalance increases. Our conclusion is that while government guarantees reduce credit risk, they do not help against short squeezes. Another way to summarize our findings here is that short squeezing is sufficiently significant for some savings banks that it wipes out the advantage they have from government guarantees.²⁸

6. Concluding remarks

This paper shows that the price a bank pays for liquidity depends on its individual liquidity position as well as the distribution of liquidity across banks. In particular, our findings are consistent with the existence of periodically occurring liquidity squeezes or the risk that such squeezes could materialize. Because the sample period of this paper is a time of relative normalcy, this shows that liquidity squeezes are not just a crisis phenomenon. The extent to which tightness in the market for liquidity is transmitted to the broader

²⁷Adding these five interaction variables does not cause notable changes to the coefficients or z -statistics of the other explanatory variables relative to what is reported in Table 7. Therefore, for the sake of brevity, we do not report the full regression results here.

²⁸In July 2001, the European Commission and the German government decided to remove state guarantees for savings banks and Landesbanks, to become effective in July 2005. We use the July 2001 event to run a difference-in-difference analysis to compare the behavior by savings banks and Landesbanks before and after the decision. We find no significant differences for any of the variables of interest.

financial markets and to the real economy, as perhaps suggested by the experience of the recent crisis, is therefore an important issue for future research.

Our finding that the price paid for liquidity increases as a bank's financial health deteriorates complements recent findings by Acharya and Merrouche (2009) that, during the recent crisis, tight interbank markets were in part caused by precautionary hoarding by poorly performing banks. These results point to the existence of market discipline in the market for liquidity and that system-wide tightness in the interbank market could result from a general deterioration in banks' financial health, not just because of a standard Akerlof (1970) adverse selection problem, but also because banks start to take action so as to not individually suffer the consequences of market discipline.

Our research can be broadened in several ways. An important question is whether banks with poor collateral are more exposed to adverse liquidity conditions and, therefore, bid higher and pay more for liquidity. Data on individual bank collateral holdings, however, are very hard to obtain.

Another important issue is how the effects we have uncovered would play out during a crisis period. For example, that small banks are more adversely affected by increases in liquidity imbalances, *ceteris paribus*, suggests that small banks would be more vulnerable in a crisis. However, because small banks tend to be less short than large banks, the net effect of a crisis could be worse for large banks than small ones. Thus, while our findings are consistent with the view that large banks have better access to the interbank market for liquidity than smaller banks, it is not clear how they would fare if this market would seize up.

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Appendix

The structure of the German banking sector

The German banking system is traditionally a system of universal banking and has a three-pillar structure. These are (with each pillar's aggregate balance sheet as a percentage of the entire banking sector in parentheses as of 2000): (1) private domestic commercial banks (40%); (2) public banks, i.e., savings banks (16%) and their regional head institutions, the Landesbanks (20%), which are jointly owned by the respective state and the regional association of savings banks; and (3) credit cooperatives (9%) and the cooperative central banks (3%), which are primarily owned by the regional credit cooperatives. Branches of foreign banks operating in Germany made up 2% of total assets.²⁹

This three pillar structure affects the way in which liquidity is reallocated in the banking sector. The public banks as well as the cooperative banking sector form a relatively closed giro system. On balance, the second-tier institutions (the savings banks and the credit cooperatives) typically achieve a significant liquidity surplus due to their retail business structure. Within the giro systems, they pass this excess liquidity onto the respective (regional) head institution. Consequently, on average in the years 2000 and 2001 savings banks held almost 75% of their interbank overnight deposits with their respective Landesbank. At the same time, only slightly more than 50% of savings banks' overnight borrowing was obtained from the regional Landesbank. Similarly, credit cooperatives granted more than 90% of their overnight interbank loans to one of the cooperative central banks, while they received only around 30% of their overnight interbank borrowing from the cooperative central banks. Conversely, the cooperative central banks obtained around 60% of the daily interbank liabilities from credit cooperatives, while Landesbanks received less than 30% of their overnight interbank loans from the regional savings banks. Instead, they obtained the majority of their short-term interbank funds from foreign banks.³⁰ Thus, the savings and cooperative banks could have less of a need to participate directly in the market for reserves than private banks.

²⁹In addition, special purpose banks (such as the Kreditanstalt für Wiederaufbau) and buildings societies (Bausparkassen) account for 7% and 2% of the banking sector, respectively. For a more detailed description of the German banking sector, see, for example, Hackethal (2004).

³⁰For a broader discussion of the interbank linkages in the German banking sector in general and within the three pillars in particular, see Deutsche Bundesbank (2000) and Upper and Worms (2004).

