Cross-Border Liquidity, Relationships and Monetary Policy: Evidence from the Euro Area Interbank Crisis*

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Abstract

We analyze the impact of financial crises and monetary policy on the supply of wholesale funding liquidity, and also the compositional supply effects through cross-border lending. For empirical identification, we draw on the proprietary bank-to-bank European interbank dataset for the 2008-2012 period, and also exploit the Lehman and sovereign crisis shocks as well as the main Eurosystem non-standard monetary policy shocks. The robust results imply that the crisis shock implies worse access, volume and spreads for overnight and even more for longer-term maturities. While after Lehman's failure liquidity supply restrictions particularly worsen for cross-border lending, effects are quantitatively stronger in the sovereign debt crisis for banks headquartered in peripherical countries. Moreover, the interbank market – as compared to other credit markets – allows exploiting the price dispersion from different lenders on identical credit contracts, i.e. overnight uncollateralized loans in the same morning for the same borrower. In particular, this price dispersion exhibits large heterogeneity across time depending on the crisis strength, across banks depending on borrower risk, and across bank-pairs depending on cross border and previous relationship lending. Importantly, this heterogeneity decreases when the Eurosystem both promises unlimited access to liquidity at a fixed price in October 2008 and announces the 3-year-LTROs in December 2011.

Keywords: Interbank liquidity, financial crises, monetary policy, credit supply, credit rationing, information asymmetry, euro area, financial globalization

JEL classification codes: E44, E58, G01, G21, G28

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1 Introduction

The global financial crisis started with the Lehman failure in September 2008 and intensified, especially in the euro area, with the sovereign debt crisis after April 2010. Both of these crisis episodes were largely centered on dry-ups in wholesale funding liquidity, in stark contrast to historical systemic crises where the runs were mainly from retail depositors. Importantly, there has been a geographical fragmentation of liquidity in global markets, notably around the sovereign debt crisis, unwinding partially the financial globalization trend of the last two decades. The main responses to combat these tensions have been central banks' non-standard monetary policy actions. Therefore, it is crucial to understand the impact of financial crises and monetary policy on the supply of wholesale funding liquidity, and also the compositional supply effects through cross-border lending.

Despite the utmost importance of this question for academia and policy, there is scant empirical evidence, mainly due to the scarcity of comprehensive micro-datasets as wholesale transactions are mostly over-the-counter. In this paper, however, we use new (borrower-lender) *bank-to-bank loan-level data* from the euro area interbank market and exploit different crisis and monetary policy shocks from 2008 to mid 2012. The strength of this data is fourfold. First, comparing to a global market, the euro area is a single currency union with strong financial integration. Moreover, it is a bank-dominated economy with a huge interbank market as compared to the U.S. federal funds market. Second, we have access to the overall bank-to-bank Target2 dataset. In contrast to U.S. payment system data, this data provides us with identifiers for interbank credit transactions and the ultimate banks involved in the transaction, which are crucial for identification of various testable predictions from the literature on liquidity supply and rationing. Third, apart from the global Lehman shock, the euro area was surrounded by substantial risks associated with various sovereigns' public debt, which gives our data larger variation in shocks. Finally, unlike the U.S. Federal Reserve's policy, the non-standard monetary policy measures conducted by the Eurosystem were until mid 2012 almost exclusively targeted to the banking sector.

We analyze the liquidity allocation in the interbank market. To identify the supply of funds while controlling for borrower fundamentals that proxy for both higher counterparty risk (Afonso, Kovner and Schoar, 2011) and lack of demand for credit, we use (borrower-lender) bank-to-bank loan level data and control for time-varying observed and unobserved borrower heterogeneity with

borrower*time fixed effects (Khwaja and Mian, 2008).[1] Moreover, to further isolate the supply of cross-border or previous lending relationship-based interbank loans, where the variation is at the bank-to-bank level, we control for liquidity hoarding and other investment opportunities at the lender level (Allen, Carletti, and Gale, 2009, Diamond and Rajan, 2009), we also add in some specifications lender*time fixed effects (Jimenez, Ongena, Peydro and Saurina, 2014). Furthermore, as we exploit the Lehman and sovereign shocks and the main non-standard monetary policy measures until mid 2012, i.e. the fixed rate full allotment and 3-year LTROs, to estimate time-varying effects of cross-border and relationship lending, we add lender*borrower fixed effects to account for the overall effects of cross-border and relationships (and other time-invariant lender-borrower characteristics such as similar business models and distance). This allows us to identify how the supply of liquidity changes during the course of the crisis (also as compared to normal times) and before and after the monetary policy changes. We analyze both the extensive and intensive margin of lending, both loan volume and spreads, and for both the overnight and the longer (than one week and up to one year)-term maturities.

Importantly, the interbank market allows a unique way of testing a crucial testable prediction from the credit rationing literature. A lender limits the supply of additional credit to a borrower who demands credit, even if the borrower is willing to pay higher interest rates for the additional funds. In contrast to other credit markets, we observe multiple financial contracts that are identical except for the interest rate: unsecured overnight loans to the same borrower during the morning from different lenders. Therefore, we can compare whether prices for these identical contracts differ and by how much, and whether differences are greater throughout crisis times (also as compared to normal times). Moreover, we can control for overall liquidity hoarding and different investment opportunities from different lenders, the volume each lender gives to a particular borrower, the number of counterparties, and analyze whether domestic (versus cross-border) or previous relationship-based lending occurs at lower prices. Controlling for all these effects, a borrower facing different prices at the same time for identical contracts must – through a revealed preference argument – not be able to borrow more from the lender with the lower price, despite that she has higher demand as it is also borrowing at a higher interest rate in the same morning from another lender. To the best of our knowledge, this way of identification is new to the literature on credit supply or rationing.[2]

[1] With the same meaning, we interchange the words interbank or bank-to-bank loans, and deposits, related to funding liquidity, throughout the whole paper.

[2] See Jiménez, Ongena, Peydró, and Saurina (2012) for a recent summary on this literature, and Berger and Udell (1992) for the classic paper on testing credit rationing.

During the Lehman crisis period, the robust results suggest that the crisis implies lower access (with a maximum reduction of about 25 percentage points) and volume in the term maturity interbank liquidity (around 80% reduction). This strong reduction was substituted partially with higher overnight interbank volumes in the initial two weeks after the Lehman failure. But, overall during the Lehman period, the effects in the overnight segment are qualitatively similar but quantitatively smaller than in the term segment: at the bank-to-bank (loan) level, the crisis implies lower access to liquidity by about 34% and volumes of granted loans (about 18%, including cross-border volume), corresponding to a reduction of about 47% (access) and 30% (volumes) at the bank level. The interbank liquidity supply restrictions during the crisis on access, spreads and volumes particularly worsen for cross-border lending. Moreover, previous strong lending relationships (defined as the lender with the highest interbank loans for a borrower before the crisis sample) provide overall better access to and higher volumes of interbank liquidity, but restrict both access and volume in crisis times, and increase prices in the same magnitude as cross-border loans (around 25 basis points).

In the sovereign debt crisis, we find similar results regarding worse access, volume and spreads in both the overnight and term segment, but there is important heterogeneity depending on the countries where the bank is headquartered. Supply restrictions to cross-border overnight interbank access in crisis times is only binding for borrowers from Troika-rescued periphery countries (i.e. Portugal, Ireland and Greece, which are IMF-EU-ECB rescued countries), with a maximum reduction of up to 15 percentage points. Moreover, for the granted cross-border loans, spreads are substantially higher for the banks headquartered in these countries (by about 30 basis points), holding everything else equal. For the large periphery (banks headquartered in Italy and Spain), access is not different as compared to banks from core countries, but spreads are about 12 basis points higher than for banks from the core. Previous lending relationships do not help in crisis times in general, nor to overall cross-border borrowers, differently from the Lehman period.

Regarding our measure related to credit rationing, we find that differences in prices from different lenders for identical contracts (overnight unsecured loans to the *same* borrower in the *same* morning until noon) significantly increase in crisis times, even after controlling for lender*time fixed effects and loan amounts. The average price dispersion in the crisis after Lehman's failure is up to 30 basis points during the morning and 50 basis points over the day relative to the minimum price paid. Moreover, we find strong borrower heterogeneity, in particular riskier banks face a substantially larger price dispersion within the same morning. Furthermore, for

the identical loan contracts, domestic loans offer lower prices as compared to cross-border loans, but not lenders with a previous lending relationship. Finally, the crisis-induced effects considerably decrease by up to 24 basis points when the ECB promises unlimited access to central bank reserves at a fixed price on October 8th, 2008.

The results related to price differences for the same interbank contract in the sovereign crisis are similar to the Lehman period, but all the quantitative effects (average increase by up to 20 basis points from minimum rate paid) are stemming from banks in the large periphery and the Troika-rescued periphery countries. The effects are substantially reduced once the Eurosystem implements in December 2011 the first three-year LTROs (all desired liquidity at a fixed rate for a period of three years against a widened pool of collateral). Moreover, the mitigating effects are stronger for banks in large peripheral countries. Similarly to the Lehman period, riskier banks have larger variation in prices paid during the same morning, in particular for banks from large periphery countries. Only for peripheral banks cross-border loans have higher prices for identical loan contracts than domestic loans. In sum, effects in the sovereign are qualitatively similar as in the Lehman case, but quantitatively weaker as compared to the Lehman crisis for banks from the core countries; banks from peripheral countries are on the other hand substantially penalized in the sovereign crisis.

Our paper adds to various strands of the academic literature. First, we contribute to the literature on monetary policy and interbank markets. Monetary policy is transmitted to the economy through the interbank market. But due to the financial crisis, liquidity allocation through the interbank market and thus the monetary policy transmission could have been impaired. For example, Gertler and Kiyotaki (2010) show how problems in the interbank market can generate real effects in the economy and how non-standard monetary policy can alleviate these problems (see also Kiyotaki, and Moore, 2012, Gertler and Karadi, 2011, 2013). At the micro level, Diamond and Rajan (2006) highlight the importance of monetary policy for banking, and Freixas, Martin, and Skeie (2011) and Allen, Carletti, and Gale (2014) argue that monetary policy can directly improve liquidity conditions in the interbank market. Despite of the importance of these questions for theory and policy, as far as we are aware, there is no other paper using micro interbank bank-to-bank level data, which is crucial for identification, to study the impact of monetary policy on interbank liquidity supply. Our evidence shows that non-standard monetary policies have a large influence on the supply of liquidity in the interbank market.

Second, we contribute to the list of studies that investigate interbank liquidity. In crisis times, there may be a reduction in interbank lending due to borrowers' counterparty risk (Flannery,

1996, Furfine, 2001, Freixas and Jorge, 2008, Bruche and Suarez, 2010, Heider, Hoerova, and Holthausen, 2010) or because of lenders' liquidity hoarding (Allen, Carletti, and Gale, 2009, Caballero and Krishnamurthy, 2008, Diamond and Rajan, 2009). In a seminal paper, Afonso, Kovner, and Schoar (2011) analyze the U.S. overnight interbank market around the days of the Lehman Brothers' bankruptcy, and show that counterparty risk plays a larger role than liquidity hoarding.[3] We make a contribution to this literature by empirically identifying ways in which the supply of interbank liquidity changes independently of borrowers' risk and lenders' liquidity hoarding; in particular, cross-border interbank loans (Freixas and Holthausen, 2005) and relationship lending (Petersen and Rajan 1994, 1995, Boot and Thakor, 1994, Freixas and Jorge, 2008, Cocco, Gomes and Martins, 2009, Bräuning and Fecht, 2012), which both are largely associated to bank-to-bank information asymmetry problems in the literature. We show that cross-border and relationship-based loans have different liquidity supply restrictions in crisis times.[4] For example, our results suggest that relationship lending may imply higher cost of credit in crisis times (consistent with hold-up problems as in Sharpe, 1990 and Rajan, 1992), but can increase the supply of cross-border loans in crisis times. Our results on cross-border loans also show a particular sensitivity of cross-border lending to crisis effects with a substantial heterogeneity depending on the country where the borrower-bank is headquartered. Moreover, also during the Lehman crisis when sovereign issues were not salient, cross-border interbank lending was also impaired. Finally, we also innovate to this literature on the way we analyze interbank liquidity, in particular identifying the effects at the loan level and controlling for borrowers' and lenders' fundamentals with a large set of fixed effects.

Third, we contribute to the literature on the identification of credit supply and rationing in credit markets. The theory of credit rationing gives a clear testable prediction (Jaffee and Modigliani, 1969, Jaffee and Russell, 1976, Stiglitz and Weiss ,1981, Bester ,1985, Mankiw, 1986, de Meza and Webb, 1987, and Holmstrom and Tirole, 1998): "it is possible that at this interest rate there is more demand for funds from borrowers than lenders are willing to provide, given alternative investment opportunities. In such a situation, there is credit rationing since there are entrepreneurs [borrowers] who would like to borrow and would be willing to pay an interest

[3] For related papers, see Furfine (2002), Allen, Hryckiewicz, Kowalewski, and Tümer-Alkan (2010), Kuo, Skeie, and Vickery (2010), Wetherilt, Zimmerman, and Soramaki (2010), Angelini, Nobili, and Picillo (2011), Iyer and Peydró (2011), and Acharya and Merrouche (2013).

[4] Afonso, Kovner, and Schoar (2013) show that substantial heterogeneity in the structure of trading relationships in the U.S. overnight interbank lending market. They also show that shocks to liquidity supply (days with low Government Sponsored Enterprise lending) lead to market-wide drops in liquidity and a rise in interest rates. However, borrowers with concentrated lenders are almost completely insulated from the shocks, while liquidity transmission affects the rest of the market via higher interest rates and reduced borrowing volumes.

rate higher than the prevailing one" (Brunnermeier, Eisenbach, and Sannikov, 2012). Given the nature of the interbank data, we observe during the morning whether a borrower is borrowing from at least two different lenders with significantly different prices for identical contracts. By a revealed preference argument, the results suggest that the borrower facing the lender with the lowest price cannot borrow more even at higher rates. Therefore, we contribute to the literature on testing credit rationing (see Berger and Udell, 1992, for a crucial contribution). Moreover, Gan (2007), Khwaja and Mian (2008), Paravisini (2008), Schnabl (2012), show that – for the identification of credit supply – loan level (borrower-lender level) data is required. These authors compare different business loans from the same borrower in the same quarter and argue that variations in lending from different banks must be associated to bank related shocks. A critique to this line of research is that business loans from different banks are different for the same firm, as maturity, collateral, and covenants are different across loans (or the moment in which the contract is written, and thus borrower fundamentals, differs) and the econometrician does not observe all the loan characteristics. Since we observe identical contracts to the same borrower from different lenders during the same morning, we can get a better measure of credit supply and test a crucial prediction from the credit rationing literature.

Fourth, we contribute to the large literature on the financial crisis that started in 2008, in particular to the euro area sovereign crisis that started in 2010 and to the reduction in financial globalization (Acharya, Drechsler and Schnabl, 2014, Uhlig, 2014, Farhi and Tirole, 2014, Sinn, 2013, and IMF, 2013). The sovereign debt crisis of the euro area in 2010 is generally perceived as being caused by increasing worries about immanent sovereign debt defaults and resulting fears of a break-up of the Euro. As a result, commentators argue that the euro area's banking system became increasingly fragmented (IMF, 2013). The geographical segmentation in banking endangered the proper functioning of the monetary transmission process in the euro area and, hence, called for various monetary policy stimuli, notably the three-year LTROs. Our results show that – even for the highly integrated interbank market – financial integration achieved in the euro area prior to 2008 was not crisis proof. More importantly, our results also show that the segmentation during the crisis is not only a result of the elevated sovereign default risks or break-up expectations. We find that also the Lehman shock particularly affected cross-border lending. This indicates that deeper uncertainties, for instance regarding counterparty credit risk at the bank-to-bank level in cross-border loans, make cross-border interbank lending particularly sensitive to crisis shocks. Our results, however, also show that unconventional monetary policy measures mitigate this segmentation.

The remainder of this paper is structured as follows. Section 2 describes our dataset. Section 3 discusses our identification strategy and econometric model. In Section 4 and 5, we present the results of the empirical analysis, first for the liquidity supply with all term loans, and second for the measure related to price dispersion in the overnight market. Section 6 concludes.

2 Data

In this section, we introduce our dataset, explain our sample and provide summary statistics on both the overnight and term segment of the euro area interbank money market.

2.1 Data Description

Target2 is the Eurosystem's payment and settlement system and carries out more than 90% of all fund flows between two credit institutions in the euro area. In particular, it is primarily used for interbank payments (91% of complete turnover) as Target2 settles on a continuous basis, in central bank money, and with immediate finality. The value of all interbank transactions executed in Target2 in four days corresponds to the total annual GDP of the euro area. As we will explain in detail in this section, from this dataset we obtain wholesale interbank funding information at the micro bank-to-bank level, which is otherwise not observable due to the bilateral nature of over-the-counter trades.[5]

Compared to the U.S. Fedwire or any other major payment system, using the interbank transaction data from Target2 has three main advantages. First, in Target2 the payment legs of interbank money market transactions are classified as interbank credit payments. This is crucial for the identification of interbank money market loans. Given that we only focus on these interbank transactions, we match the two legs (the initial payment and repayment) of an interbank loan to obtain further details on the trade (prices and maturities) by employing a refined version of the Furfine (1999) algorithm as developed by Arciero, Heijmans, Heuver, Massarenti, Picillo, and Vacirca (2013). One major advantage of this algorithm is that is constructed so as to identify also term interbank loans of up to one year.[6]

[5]Money market transaction may also be settled via EURO1, the second yet much smaller large value payment system with a daily turnover of less than 8.3% of Target2 and only 65 participating banks as compared to about 4500 participants in Target2.

[6]For an explanation and validation of the algorithm, refer to Arciero et al. (2013). For robustness reasons, we try several parameter combinations to ensure that our findings are not driven by the choice of the algorithm. In particular, we run the algorithm for various symmetric and asymmetric corridor widths around the average European money market interbank rate, Eonia. Furthermore, we employ a corridor-free approach on overnight loan payments with a natural zero lower bound (in analogy tode Frutos, Garcia, Heider, and Papsdorf (2014). Our main results remain qualitatively unaffected by these changes to the algorithm-based identification technique.

Second, Target2 interbank credit payments reflect for each loan the information on the ultimate lender and borrower, while e.g. Fedwire data have only information on the settling institutions. This is key for the identification of the borrower's and lender's country of origin to identify cross-border interbank loans and banks headquartered in crisis countries and lending relationships. Third, the algorithm-based estimation quality is checked against actual loans from some countries using information at the transaction level from either supervisory datasets (Bank of Spain) or from private datasets (Italy's e-MID). Arciero et al. (2013) and de Frutos et al. (2014) validate the Target2 interbank loan data using the Italian uncollateralized e-MID trading platform and the Spanish unsecured post-trading platform MID, respectively. The quality check reveals that the Target2 interbank loan data matches very well the *actual unsecured* Italian and Spanish money market data (pairing incorrectly less than 1% of payment legs as interbank loans), which also highlights the unsecured nature of the interbank transactions settled via Target2. The type 2 error amounts to less than 8% in Arciero et al. (2013) and to 11.7% in de Frutos et al. (2014). Hence, the algorithm roughly could not find about one tenth of the loans reported in the official MID data, because of, for instance, principal loan amounts of less than EUR 1 million, non-rounded loan amounts, institutional set up of MID (aggregation of payments within 30 minutes before sent to Target2), or the loan not being settled in Target2. The quality of the interbank data for U.S. and U.K. is not easy to validate at the transaction level, as there is no respective interbank transaction data available (Armantier and Copeland, 2012).[7]

We observe all interbank loans between two credit institutions settled via Target2 in the period from June 2008 (when Target2 starts and has consistent data) through mid 2012 (before the interest rate paid on reserves was set to zero). The data is at the loan level, with information on the ultimate borrower and lender identity, the amount lent, the interest rate and the maturity as well as the time stamp of the loan (up to a millisecond). In our analysis, we use cross-border operations to proxy for asymmetric information and other related financial frictions. Therefore, we only analyze cross-border operations between banks that do not belong to the same holding group. That is, any loan between, say, Deutsche Bank (Germany) and, say, Santander (Spain) will be reflected in our dataset and considered as cross-border trade while a loan between, say, Deutsche Bank (Germany) and, say, Deutsche Bank (Spain) will not be included.[8] Also, to account for the different branches and subsidiaries, we have consolidated banks on the first eight

[7]Kovner and Skeie (2013) assess the U.S. data using banks' fed funds borrowing as reported in the quarterly FRY-9C filings. They show that flows of overnight loans extracted from Fedwire payments data explain 78% of these outstanding overnight loans at quarter ends reported by big U.S. bank holding companies.

[8]We have left these cross-border trades within a bank holding group for future research.

digits of the respective BIC (from the initial eleven digits).

Furthermore, we use bank-specific end-of-year balance sheet data from Bankscope, in particular bank size (assets) and capital ratio (equity). We merge this dataset with our money market database for those banks, for which we have balance sheet information from 2007 through 2012. This pares down the number of distinct banks to a total of 305 borrowing and 348 lending institutions from initially 556 borrowing and 647 lending banks.[9] To our loan level interbank dataset (which comprises for every loan the time stamp of the transaction, the information on the ultimate lending and borrowing party, the maturity, price, and volume of the loan), we add for each borrower bank lagged (annual) balance sheet information. Also, we include as our time-varying risk measure the daily three-month spread between the Euribor and the overnight index swap (Euribor-OIS) and the five year sovereign credit default swap (CDS) of the country where the borrower is headquartered. We obtain this information from Bloomberg and Markit, respectively.

For our analysis, we split our data into two different sub-samples to account for the Lehman crisis and the European sovereign debt crisis, respectively. The period from 18 August 2008 through 9 November 2008 (60 days, with 4 weeks before and 8 weeks after Lehman's failure) defines henceforth the Lehman period and the sample from January 2010 through December 2011 (104 weeks) determines the sovereign (debt crisis) period hereafter.[10] Give the short time period for Lehman, we estimate all our models with data at daily frequency. For the longer sovereign crisis period this is for most specifications computationally not feasible and we therefore use weekly data and resort to daily data only for the regressions, where we study the price dispersion during the morning. In case of multiple loans for the same pair during one day (or week), we aggregate volumes and compute the quantity-weighted interest rate. For simplicity we also refer to aggregated quantities as loans and loan characteristics throughout the whole paper.

2.2 Summary Statistics

For the overnight interbank money market, we observe 203 and 265 distinct borrowers and lenders yielding a total of 3032 distinct bank pairs during the Lehman sample. This corresponds to a total of 13661 overnight loans and a daily average of 228 loans. On average, the daily

[9] Another reason for the reduction of the number of banks is our identification strategy, which we explain in Section 3. For robustness reasons, we estimate our models also on the initial number of banks and find that our results remain qualitatively unchanged.

[10] Note that our analysis does not depend on the choice of the estimation sample length. In robustness checks, we replicate our analysis on different subsamples, both in terms of the time horizon and the selection of banks. In particular for the Lehman period, we check whether various sample lengths around the failure of Lehman Brothers change our results and if so how.

volume borrowed per loan amounts to EUR 87.04 million. The spreads paid vary on average with a standard deviation of 21 basis points around the daily mean rate (Panel A of Table 1). Each bank borrows on average EUR 351.49 million per day with about 36% coming from foreign lenders. Our average borrowing (lending) bank's total assets account for EUR 164.55 (127.05) billion with an equity ratio of 6.9% (8.0%).

For the period after 2010 (sovereign crisis sample), our dataset reflects transactions between 286 distinct borrowing and 326 lending banks. This amounts to a total of 5365 different bank pairs and 60695 reported loans. On average, 584 loans are traded per week, where the weekly mean loan volumes equal EUR 177.21 million. The interest rate paid for an overnight loan deviates on average by 15 basis points around its weekly mean. Each bank borrows on average funds in the amount of EUR 997.32 million per week, with about 14.4% coming from foreign lenders. The average borrowing (lending) bank's total assets is EUR 122.50 (106.99) billion with an equity ratio of 7.4% (8.1%).

For term interbank loans, i.e. loans with a maturity larger than one week, we have data on 109 different borrowers that at the same time are also borrowing in the overnight segment during the Lehman period. On average, 24 banks borrow EUR 89.16 million per day and pay prices that vary daily with a standard deviation of about 25 basis points around the daily mean, see the Panel B of Table 1. Compared to the overnight segment, the average borrowing bank in the term segment has more assets (EUR 272.94 billion) and is on average less capitalized (6.1%). For the sovereign period, we observe a total of 186 distinct banks. An average of 12 borrowing banks is borrowing on a weekly basis at rates of about 27 basis point on average around the weekly mean. On average, a bank borrows EUR 115.14 million per week in the term interbank market. Also during the sovereign period the average borrowing bank that borrows in the term interbank market has more assets (EUR 175.70 billion) and has a lower equity ratio (7%) than banks active in the overnight segment only.

3 Empirical Strategy

This section describes how we identify the impact of financial crises and monetary policy on the supply of wholesale funding liquidity, and also heterogeneous effects depending on cross-border, relationship lending and borrower bank risk. We therefore elaborate on the empirical strategy along with the definitions of variables and the econometric equations. For empirical identification, we crucially draw on the aforementioned data on borrower-bank-to-lender-bank

interbank loan-level data from mid 2008 to mid 2012.

In our empirical strategy we rely on two sets of analyses. The first one is based on all lending conditions in the interbank market, while the second one is centered on loan prices and is new for the literature on credit restrictions. On the first analysis, we analyze access in interbank overnight funding (i.e. the extensive margin), and, conditional on having granted an interbank overnight loan, the associated volume and interest rate (i.e. the intensive margin). As we explain in detail below, we do this analysis at the loan (borrower-bank-to-lender-bank) level with a strong set of fixed effects to identify credit supply (Khwaja and Mian, 2008), but also at the (borrower) bank-level to analyze any potential substitution effects in credit supply reduction from some banks or from some lending relations (e.g. in the cross-border segment). Given the large volume of overnight lending activity, where there are several loans to the same borrower from different lenders at the same time, as compared to the term (beyond one week) lending, we can only do the analysis on the loan level with a substantial set of fixed effects in the overnight segment, while we do the analysis at the borrower-bank level on both overnight and term borrowing.

The second analysis is centered on interbank loan prices. As compared to other credit markets, in interbank markets there are multiple identical financial contracts if we restrict the analysis to the overnight segment: overnight unsecured loans to the same borrower during the same morning (or day) from different lenders. Substantial differences in prices for the same borrower in the same morning from different lenders imply – through a revealed preference argument – that the borrower has limits to additional borrowing from the lender charging the lowest price. These differences in prices, apart from identifying credit restrictions, shed light on a crucial testable prediction that arises from the credit rationing literature: a lender limits the supply of additional credit to a borrower who demands credit, even if the latter is willing to pay higher interest rates for the additional funds. We analyze the variation in interbank loan prices for the same borrower during the morning (or day), who offers lower prices (domestic vs. cross border lending; relationship lending), whether the price dispersion is related to borrower risk, and how these different heterogeneity margins vary over the financial crisis and depend on non-standard monetary policy operations.

The time variation of the crisis and monetary policy is a crucial component in our identification strategy. Therefore, we consider both the Lehman and the sovereign debt crisis. First, cross-border, sovereign and euro area problems were not stressed during the Lehman period. Also, the Lehman's failure was more exogenous to the euro area system, while there is a substantial heterogeneity in the euro area crisis that we exploit in our analysis. Furthermore, there

is one crucial monetary policy change in each period, with the introduction of the fixed rate full allotment policy as of 15 October 2008 (announced on the 8 October 2008) and the first three-year long term refinancing operation (LTRO) in December 2011 (announced on 8 December 2011 and effective on 22 December 2011). In the context of the first measure, the Eurosystem allowed banks to borrow as much as they wanted (against eligible collateral) at a pre-announces fixed rate. Before the introduction of these measures, the Eurosystem conducted a multi-unit price-discriminatory auction. That is, it decided the volume of liquidity to provide within a 'pay-as-you-bid' auction setup, where banks submitting bid-quantity schedules received central bank reserves in descending order of their bids until the amount deemed appropriate by the Eurosystem was exhausted. The three-year LTRO also follows the fixed rate full allotment but grants central bank loans for the period of three years (rather than weeks or months) against a wider set of eligible collateral. See Bundesbank (2014) for the euro area monetary operations throughout the crisis.

3.1 Supply of Interbank Liquidity and Loan Terms

To identify the supply of interbank liquidity, we control for borrower-specific fundamentals that proxy for both higher counterparty risk (see Afonso, Kovner and Schoar, 2011, and the references therein on interbank counterparty risk) and lack of demand for credit. Therefore, we use borrower-bank-to-lender-bank loan level data and control for time-varying observed and unobserved borrower bank heterogeneity with borrower*time fixed effects (Khwaja and Mian, 2008). Moreover, to further isolate the supply of cross-border (versus domestic) and relationship-based interbank loans, where the variation is at the bank-to-bank level, we control for lenders' investment opportunities and liquidity hoarding (Allen, Carletti, and Gale, 2009, Diamond and Rajan, 2009). Therefore, we also add in some specifications lender*time fixed effects (Jimenez, Ongena, Peydro and Saurina, 2014). Furthermore, as we exploit the Lehman and sovereign crises period shocks to estimate time-varying effects of cross-border and relationship lending, we can add borrower-lender fixed effects to account for time-invariant effects of cross-border and relationships (and other persistent borrower-lender characteristics such as similar business models, being part of a formal liquidity network, i.e. as public banks and credit cooperatives, and distance). This allows us to identify how the supply of liquidity changes during the course of the crisis (also as compared to normal times).

For our estimation we restrict our loan-level sample as follows. First, we exclude all loans that involve on either the borrowing or lending side banks that traded with less than two coun-

terparties in our estimation sample. So, the remaining loans in the restricted sample are from borrowers and lenders who receive/provide each credit from/to at least two different banks in our estimation period. Second, we prune down the dataset further by excluding those loans to borrowing banks that do not receive funding during our reference period. That is, all remaining loans are to borrowing banks that have trades before our estimation period and at least two different counterparties in our estimation sample. For the overnight loan data, our econometric specification then takes the following form:

$$\begin{aligned}\text{Loan}_{i,j,t} = \beta_1 \text{Crisis}_{j,t} + \beta_2 \text{Crisis}_{j,t} \times \text{Cross-border}_{i,j} + \beta_3 \text{Crisis}_{j,t} \times \text{Relationship}_{i,j} \\ + \beta_4' \cdot \text{Crisis}_{j,t} \times x_{j,t} + \beta_5' x_{j,t} + \text{fixed effects} + \epsilon_{i,j,t}, \end{aligned} \tag{1}$$

where $\text{Loan}_{i,j,t}$ refers to the loan (both extensive and intensive margin) provided by lender i to borrower j on day (or week) t. For each given bank-pair in the restricted sample, we define for any given day a binary variable ($\text{Access}_{i,j,t}$) that equals the value one if that bank pair trades and zero otherwise. We refer to this binary variable as the extensive margin of credit. If there is a trade ($\text{Access}_{i,j,t} = 1$), then we also observe the loan conditions, i.e. rate and volume. If no trade occurs, then we do not have any information on the intensive margin of credit.

For the intensive margin, $\text{Loan}_{i,j,t}$ reflects the loan conditions, price and volume , provided that credit has been granted. We measure the price ($\text{Spread}_{i,j,t}$) as the spread between the rate paid for the granted loan and the daily unsecured overnight mean interest rate of all loans in the sample, and the volume ($\text{Volume}_{i,j,t}$) as the logarithm of the respective loan amount in EUR millions from lender i to borrower j. $\text{Crisis}_{j,t}$ refers to the time-varying crisis variable, i.e. the three-month Euribor-OIS spread ($\text{Crisis}_{j,t} = \text{Crisis}_t$ for all j) for the Lehman period and to the five-year sovereign CDS spread of the country, where the borrowing bank j is headquartered for the sovereign crisis sample.[11]

$\text{Cross-border}_{i,j}$ is a dummy variable that equals the value one whenever the borrower and

[11] We use a five-day moving average of the daily CDS spreads as daily volatility in spreads might be related to market liquidity issues. Also we have chosen different proxies to account for both the financial and sovereign debt crisis. For the Lehman period, for instance, we employ the three-month Euribor-Eurepo spread as well as shorter and longer dated Euribor-OIS spreads. The Eurepo is an European reference rate for the collateralized segment of the interbank money market in the euro area. Throughout the crisis, it has been used widely as an alternative way to account for elevated risk premia in the euro area interbank market. For more details, see `www.eurepo.org`. Also, we use a binary variable instead of the three-month Euribor-OIS spread that takes the value one as of September 15, 2008 and zero before. For the sovereign period, we replace the borrower's country CDS by the arithmetic mean of the periphery country CDS spread. Also, we compute each borrower's country CDS as a difference to the German CDS. Moreover, we additionally use dummy variables for the different stages of the sovereign debt crisis corresponding to the sub-periods marked by the dates 23 April 2010 (Greece's first recourse to Eurosystem's financial stability facility), 1 July 2011 (increased refinancing problems by Italy and Spain) and the announcement of the first three-year LTRO in December 2011. All these robustness checks do not change our results qualitatively.

lender banks are from different countries and zero otherwise.[12] For the sovereign crisis period, we study the heterogeneity of cross-border overnight interbank loans depending on the country where the bank is headquartered. More precisely, we study the heterogeneity of core (list countries), large periphery (banks in Spain and Italy), and Troika-rescued periphery (Greece, Portugal, and Ireland) country banks. We compute these variables as binary variable if the bank is headquartered in one of the respective country groups, and zero otherwise. Relationship$_{i,j}$ is a binary variable that takes the value one for the lender i from whom the borrower j obtained most of its overnight funding during the pre-crisis reference period which we choose as follows: For the Lehman period estimations, we construct the relationship variable on the basis of the period from 1 June 2008 through 9 August 2008.[13] Given that our data starts in June 2008, we use a longer reference period for the sovereign sample ranging from 7 September 2009 until end of 2009 and results are very similar if we take almost 18 months of data (from June 2008 to December 2009). We compute lending relationships from data before the actual estimation period to ensure that the explanatory variables are predetermined and not endogenous.[14] The vector $x_{j,t}$ reflects a set of lagged borrowing bank-specific (annual) control variables, i.e. each borrower's beginning-of-the-year asset size and equity ratio, which we add when we do not control for borrower*time fixed effects. Further, to study heterogeneous effects of cross-border or relationship lending depending on bank and bank-pair characteristics in normal and crisis times, we also include interaction terms of our main variables. That is, we use Cross-border$_{i,j}$*Relationship$_{i,j}$ and Crisis$_{j,t}$*Cross-border$_{i,j}$*Relationship$_{i,j}$ to measure how previous linkages with banks abroad affect both the extensive and intensive margin of credit during normal and crisis times. Furthermore, we include further interactions between the cross-border dummy, the relationship lending variable, and the borrower's asset size and equity ratio.

We estimate Equation (1) by ordinary least squares (OLS).[15] We first estimate our models

[12]For cross-border lending, we further study heterogeneous effects depending on the lender and borrower's origin. In particular, we analyze the following different cross-border lending patterns: (i) from core to periphery country banks, (ii) from periphery to core country banks, and (iii) from periphery to periphery country banks. None of these robustness checks affect the results.

[13]The Eurosystem launched its Target2 system on 1 June 2008. The reference period ends with the reserve maintenance period before the Lehman failure.

[14]In robustness checks, we use different relationship measures at the bank-to-bank level, in particular (i) the number of loans exchanged between any two banks, (ii) the borrower preference index (BPI) (according to Cocco, Gomes, and Martins, 2009, and Tölö, Jokivuolle,and Matti, 2014), which for each borrower measures the fraction of borrowing obtained from each lender, and (iii) a censored version of the BPI where all but the highest BPI are set to zero for each borrower.

[15]The choice to estimate linear regression models is due to the large set of fixed effects that we use in the analysis and that the key coefficients of interest are the interaction terms between the crisis and the cross-border and relationship variables. In robustness checks we ensure that our main results are not driven by potential selection bias using the sample selection model by Kyriazidou (1997).

without any fixed effect controls to study all the effects related to liquidity and end with the representation in Equation (1) that refers to the specification with the strongest set of fixed effects (and thus with our strongest identification). We compute heteroskedasticity robust standard errors clustered at the bank-pair level.[16] We saturate the regressions with fixed effects progressively to also analyze the different effects without such strong set of controls and to analyze some important variables such as the direct effect of the crisis variable and the level effects of cross-border and relationship lending. In the specification with the strongest set of controls, the pair-wise time-varying component of our dependent variables remains the only dimension yet to be explained. This allows us to analyze how interbank liquidity supply (total and compositional effects) changes over time. The empirical identification of these fixed effects relies on the comparison of the loans to the same borrower at the same time from different lenders, the comparison of loans from the same lender at the same time to different borrowers, and the comparison of loans between the same pair of banks at different points in time. This is feasible for the overnight segment, but in the less active term interbank loan market, there are too few observations, where both the borrower and the lender have multiple counterparts at the same time with the same maturity.

Finally, given that some interbank loans may be substituted throughout the crisis in response to changes to e.g. supply of cross-border or relationships loans, it is important to also study the interbank liquidity changes at the (borrower) bank level. At the bank level, our access variable captures the occurrence of overnight borrowing for each bank in the sample. We measure the price of total interbank borrowing with the volume-weighted average spread between the rates paid and the daily unsecured overnight (volume-weighted) mean price. The loan volume is calculated as the logarithm of the total borrowing amount in period t in EUR millions. Similar to our bank-to-bank level analysis, we mainly focus on overnight unsecured interbank borrowing. But, for any bank that borrows overnight, we also study whether it borrows in the term segment during the same day (or week). To that aim, we define for any given day (or week) during which a bank borrows in the overnight interbank market a binary variable that equals the value one if the bank also borrows in the term segment during the same day (or week) and zero otherwise (i.e. the bank only borrows overnight). This will define our extensive margin of term credit (Term access$_{j,t}$). Conditional on borrowing in the term segment, we also observe the intensive margin of credit, the price and the volume of credit. We compute the volume in logs of the total

[16] Clustering of standard errors at the bank (borrower or lender) level yields the same findings regarding our main variables.

traded term interbank loan amount in EUR millions. We however compute the price of the term interbank loan as a difference to the average rate in the respective maturity bucket.[17]

We analyze interbank credit at the bank level using the following linear model

$$\begin{aligned} \text{Loan}_{j,t} &= \beta_1 \text{Crisis}_{j,t} + \beta_2' x_{j,t} + \beta_3' \text{Crisis}_{j,t} \times x_{j,t} \\ &+ \beta_4 \text{Crisis}_{j,t} \times \text{Cross-border borrowing ratio}_j \\ &+ \beta_5 \text{Crisis}_{j,t} \times \text{Borrowing concentration ratio}_j + \text{fixed effects} + \epsilon_{j,t}, \end{aligned} \tag{2}$$

where $\text{Loan}_{j,t}$ follows the same rationale of Equation (1) and reflects several margins (access, spread, and volumes) of credit granted to the borrower j at time period t. We estimate these equations for both the overnight and term interbank loan market. But different from our bank-to-bank level specification, Cross-border borrowing ratio_j measures the access to cross-border interbank markets captured by total cross-border interbank borrowing relative to the borrower's asset size.Borrowing concentration ratio_j the total overnight interbank loan amount that borrower j obtains from its most important (in terms of loan amount) lender over a reference period as a share of its total interbank borrowing during the same reference period. We use the same pre-crisis-reference periods as in the loan level specifications. The vector $x_{j,t}$ contains bank balance sheet characteristics. We estimate Equation (2) using OLS and saturate the regressions progressively with fixed effects.

3.2 Price Dispersion and Monetary Policy

The second part of our empirical analysis is focused on prices of interbank loans and we motivate it with the theory of credit rationing. This theoretical literature gives a clear testable prediction: a lender limits the supply of additional credit to a borrower who demands credit, even if the borrower is willing to pay higher interest rates for the additional funds. For example, Brunnermeier, Eisenbach, and Sannikov (2012) argue in their survey on macro and financial frictions as follows: "it is possible that at this interest rate there is more demand for funds from borrowers than lenders are willing to provide, given alternative investment opportunities. In such a situation, there is credit rationing since there are entrepreneurs [borrowers] who would

[17] We construct four different term interbank buckets. The first one contains all loans with maturity larger than one week and less than 31 days. The second bucket includes all loans with maturity larger than 31 days but less or equal than 60 days. The third bucket contains loans with maturity larger than 60 days but less than 91 days. The fourth classification covers the longest-dated loans, with maturity larger than 90 days. Our results do not depend on the choice of these bucket sizes. In each one of the aforementioned buckets, the average daily aggregate market volume amounts to EUR 1340 million (7 to 31 days), EUR 445 million (31 to 60 days), EUR 192 million (60 to 90 days), and EUR 456 million (beyond 90 days), respectively during our Lehman period and EUR 253 million, EUR 75 million, EUR 35 million, and EUR 83 million, respectively, during the Sovereign sample.

like to borrow and would be willing to pay an interest rate higher than the prevailing one."[18]

Suppose we observe overnight unsecured interbank loans to the same borrower during the same morning (or day) from different lenders and then compare whether prices differ significantly. A borrower facing substantially different prices at the same time for *identical* contracts must – through a revealed preference argument – not be able to borrow more from the lender with the lowest price. But the borrower wants more credit and is willing to pay a higher price for the additional funds since the borrower is obtaining more credit at a higher interest rate from another lender. Are the prices significantly different? If so, why does the borrower not borrow more from the bank with the lower price? Is it because the lender with the lower price only lends a limited amount, i.e. is it hoarding liquidity, or because some lenders have different investment opportunities? Is it because some lenders provide loans of larger volume and therefore charge higher spreads? How does the heterogeneity in prices for the same borrower during the same morning (or day) vary over time (across the crisis and depending on monetary policy), over borrower banks (riskier versus less riskier) and borrower-lender pairs (depending on cross-border or relationship lending)?

Moreover, monetary policy affects credit rationing tensions. Both the theoretical (in the seminal paper by Jaffee and Modigliani, 1969) and the empirical literature (Berger and Udell (1992)) on credit rationing argue that credit rationing has an important role for the transmission of monetary policy. Berger and Udell (1992) also explain that "the advocates of the availability doctrine in the 1950's suggested that monetary policy may operate in part through a rationing channel rather than an interest channel (e.g. Kareken, 1957 and Scott, 1957)". Moreover, Harrod (1969) goes on to argue that the main channel through which a tightening of monetary policy curtailed economic activity is through credit rationing, saying also that this imperfection of the capital market makes monetary policy a powerful weapon. The literature on the credit channel of monetary policy explained by Bernanke and Gertler (1995) gives more importance to the external finance premium rather than availability of liquidity. However, since the crisis that started in 2008, there are more papers on the importance of monetary policy for credit and liquidity constraints (Freixas, Martin, and Skeie, 2011, Allen, Carletti, Gale, 2009, and also the macro papers on macro-finance summarized by Brunnermeier, Eisenbach and Sannikov, 2012). We therefore ask whether the main two non-standard monetary policies introduced by the ECB in our sample affect the difference in prices at the borrower-time level.

[18] See Jaffee and Modigliani (1969), Jaffee and Russell (1976), Stiglitz and Weiss (1981), Bester (1985), Mankiw (1986), de Meza and Webb (1987) and Holmstrom and Tirole (1998).

Another implication from the credit rationing literature is that asymmetric information problems could be partly driving the results (Stiglitz and Weiss, 1981). In this case, the difference in lenders' pricing may be related to information asymmetry problems between the lender and the borrower. Freixas and Holthausen (2005) and Freixas and Jorge (2008b) show that both domestic (vs. cross-border) and relationship-based loans are important mechanisms to reduce information asymmetry problems between borrowers and lenders in the interbank market. We therefore test if domestic (vs. cross-border) loans or by relationship lenders reduce the difference in prices at the borrower level (our above measure related to credit rationing).

To answer the above questions we follow to approaches. First, we use prices of different loans to the same borrower in the same time period to compute a statistic that measures the degree of price dispersion at the borrower-time level and analyze the heterogeneity across time (the crisis and monetary policy) and across borrower banks (riskier borrowers proxied by their overall borrowing spread). Second, we analyze at the loan level whether the differences in prices for the same borrower in the same period (morning or day) dare different for cross-border loans, relationship loans and loans of different volumes.

For the analysis of the time and borrower bank heterogeneity, we construct the statistic at the borrower-time level as follows. We first limit our bank-to-bank level data to loans from borrowers who are engaged in loans with at least two lenders in the early morning (7am-12pm).[19] Moreover, we keep only loans from lenders who grant loans to at least two different (borrower) banks during the early morning. As the lender gives more funds to at least one other bank, this restriction ensures that the lender is not liquidity constrained. However, part of the remaining price variation can be due to liquidity hoarding by some lenders or because of lenders' different outside investment options (Brunnermeier, Eisenbach and Sannikov, 2012). Therefore, in some regressions we further clean the different lending rates to the same borrower in the same morning of these lenders' conditions in the following way. We regress the loan rate by each borrower-lender pair in each time period on lender*time fixed effects, and the residual will be the loan rate to the borrower during the morning (or day) from a lender cleaned by unobserved and observed time-varying lender heterogeneity.

On the basis of the residuals, we construct our measure based on the volume-weighted difference in prices stemming from the residuals (compared to the minimum one) in the different overnight interbank borrowing from different lenders to the same borrower during the same morn-

[19] Imposing the same restrictions on the term interbank market leaves too few observations, which is why we focus on the overnight bucket while studying this margin.

ing.[20] We denote this variable by Price dispersion$_{j,t}$. Note that we build this variable on the basis of *bank-to-bank micro* transaction-level information. The interpretation of this measure is straightforward. It captures the average increase in funding costs (in basis points) for the total amount borrowed on a given morning from the cheapest price paid during the same morning.

To analyze how the two main non-standard monetary policy measures introduced by the Eurosystem affect our measure related to credit rationing, we estimate the following model with OLS

$$\text{Price dispersion}_{j,t} = \beta_1 \text{Crisis}_{j,t} + \beta_2 \text{Policy}_t + \beta_2' x_{j,t} + \text{fixed effects} + \epsilon_{j,t}, \tag{3}$$

where Policy$_t$ is a binary variable that equals the value one as of the Eurosystem's announcement of the fixed-rate full allotment (Full Allotment$_t$) policy (for the Lehman sample) and the three-year longer-term refinancing operation (LTRO$_t$), respectively (for the sovereign sample), until the sample end, and zero otherwise.[21] The other bank variables are the same as in Equation (2). For our monetary policy analysis we also use the measure of price dispersion computed based on all loans until 6 pm that are not cleaned for lender*time fixed effects and volumes as we are interested in the overall monetary policy effect on price dispersion.

To further analyze the bank-level heterogeneity and to answer whether worse borrowers have higher price dispersion, we analyze the different subsamples of the crisis with time fixed effects. Given that the bank variables from Bankscope are only based on balance sheets and cannot capture in real time (daily) the solvency and risk of the borrowers, we use the average spread paid by each borrower on the previous day as a proxy for borrower bank risk. As the spreads may depend on the level of borrowing, we control for the total amount borrowed during the morning and the number of lenders during the morning. We estimate the following regressions for the q^{th} percentile

$$\text{Price dispersion}_{j,t}^q = \beta_1^q x_{j,t} + \beta_2^q \text{Borrower risk}_{j,t} + \text{fixed effects} + \epsilon_{j,t}^q, \tag{4}$$

where Borrower risk$_{j,t}$ is the quantity-weighted average interest rate spread to the daily (volume-weighted) mean price of all overnight interbank loans. We control for the total amount borrowed

[20] Alternatively, we also compute the (i) volume-weighted standard deviation of interest rates as well as (ii) the (equally-weighted) standard deviation of interest rates. Further, we compute the (iii) range on interest rates paid by a borrower during any given morning. All these measures of dispersion are highly correlated and lead to very similar results for our estimations. We choose to present results based on the volume-weighted deviation of the minimum interest rate mainly due to the ease of interpretation, i.e. the average increase in funding cost for the total amount borrowed.

[21] The Eurosystem announced the FRFA-policy on 8 October 2008, see `http://www.ecb.europa.eu/press/pr/date/2008/html/pr081008_2.en.html`. The first three-year LTRO was announced on 8 December 2011, see `http://www.ecb.europa.eu/press/pr/date/2011/html/pr111208_1.en.html`.

(defined as the logarithm of the total loan amount borrowed during the morning), for the number of lenders for the borrower in the morning, and for the bank-specific vector $x_{j,t}$ (which includes both the borrower's lagged asset size and equity ratio). We run these quantile regressions to estimate the 50th, 75th, and 90th percentile ($q = 50, 75, 90$) of the distribution of our credit rationing related measure of price dispersion conditional on bank characteristics. In a next step, we study the heterogeneity of price differences at the borrower-lender level, in particular the pricing of cross border and relationship loans. We analyze in regressions with borrower*time fixed effects whether interbank prices differ from different lenders to the same borrower in the same morning. Moreover, given that some lenders may be liquidity constrained or may have different investment opportunities (see above the testable prediction from theory), we also control for lender*time fixed effects. Additionally, we also control in some interest rate regression models for the overnight interbank loan volume given by each lender to the same borrower in the same morning as some lenders may provide higher volumes and thereby ask for higher spreads. The model for these regressions is then as follows:

$$\begin{aligned} \text{Spread}_{i,j,t} &= \beta_1 \text{Cross-border}_{i,j} + \beta_2 \text{Relationship}_{i,j} \\ &+ \beta_3 \text{Cross-border}_{i,j} \times x_{j,t} + \beta_4 \cdot \text{Relationship}_{i,j} \times x_{j,t} + \text{fixed effects} + \epsilon_{i,j,t}, \quad (5) \end{aligned}$$

where the right-hand-side variables are computed in the same way as in Equation (1). As opposed to the regressions discussed in Equation (1), we do not interact our key variables with crisis proxies as this is already done in the previous equations and our interest now is *not* a difference in difference analysis, but rather whether in the same period there are differences in prices for the same borrower. We could report this analysis for each day in our sample, but for computational ease, we group similar days and run the regressions for different subsamples before and during the Lehman and sovereign crises sample. Given the main developments of the crisis and monetary policy actions, we have chosen for both our Lehman and sovereign crisis periods four subsamples each. For the analysis of the Lehman failure, we look into the following subsamples: (i) four weeks before Lehman failure, (ii) first two weeks post-Lehman, (iii) third to fourth week post Lehman, and (iv) fifth to eighth week post-Lehman. For the sovereign crisis samples, the sub-periods are: (i) January 2010 through April 2010, i.e. before Greece sought its first support, (ii) May 2010 through June 2011, with the intensification of the sovereign crisis also for Italy and Spain, (iii) second half of 2011, and (iv) January 2012 through April 2012 covering the post-three-year-LTRO period.

4 Results on Supply of Interbank Liquidity

and Loan Terms

In this section, we present the results on the supply of interbank liquidity and its changes during the crisis, both at the bank-to-bank (loan) level and at the bank level. We discuss first the results of the Lehman period then those of the sovereign crisis period.

4.1 Evidence for the Lehman Period

Panel A of Table 2 presents the estimated coefficients of the bank-to-bank level regressions for our Lehman sample.[22] We first analyze the time variation of access and loan conditions during the crisis. An increase of the Euribor-OIS spread implies a significant drop in bank-to-bank funding access, as Column (1) shows, amounting to a maximum of 4 percentage points at the peak of the Euribor-OIS spread (-1.98×2).[23] Compared to the average loan probability of 5.9% before Lehman's failure, this maximum change corresponds to a reduction of access by about 34%. Conditioned on having access to interbank liquidity, we find no statistically significant effect of the crisis on interbank prices and volumes of granted loans. Therefore, the strongest effects are on the extensive rather than the intensive margin of interbank liquidity.[24]

We also analyze the compositional effects of the supply of interbank liquidity with respect to cross-border and previous relationship transactions. We find that cross-border loans are about 2.4 percentage points less likely than domestic loans (i.e., between banks headquartered in the same country). This holds after controlling for borrower, lender and time fixed effects, as Column (2) and (3) show. In fact, the economic impact increases further and amounts to about 3.6 percentage points lower access. In Column (3), we also include the interaction terms between the cross-border dummy and the Euribor-OIS spread, and find that an elevated Euribor-OIS implies an additional reduction of cross-border interbank lending of up to 2 percentage points at the peak of the Euribor-OIS. In Column (4), we present the estimation results for our full model including both borrower*time and lender*time fixed effects as well as borrower-lender pair fixed effects. The level effects of cross-border liquidity are absorbed in the pair-fixed effects, but the results of the interaction term with the Euribor-OIS spread confirm the additional liquidity supply restrictions of up to 2 percentage points during the crisis.

For the intensive margin, Column (8) and (12) imply that the supply of interbank liquidity

[22] Robust t-statistics are shown in parentheses and are based on standard errors clustered at the bank-pair level and ***, **, * state the statistical significance at p<0.01, p<0.05, p<0.1.

[23] The Euribor-OIS spread increased after Lehman with the peak value of 2.069% on 10 October 2008.

[24] These results are based on the restricted sample as described in Section 3 All of our results presented here are similar for the non restricted sample.

worsens for cross-border trades during the crisis. There is a supply reduction in volumes of granted cross-border loans (compared to domestic loans) by 18% and a supply tightening of prices by roughly 13 basis points at the peak of the crisis. Note that it is important to control for borrower and lender heterogeneity, compare Column (9) with (10) or (11). Also because cross-border loans could have higher volumes just because cross-border borrowers are for example larger banks. All in all, the results suggest a strong impact of the Lehman crisis on the supply of cross-border interbank liquidity.

The results on previous lending relationships suggest that lenders provided overall better access (10 percentage points more likely) and higher granted volumes (by 40%) to their previous borrowers. During the crisis, however, previous relationship lenders restrict both funding access and granted loan amounts. That is, the overall positive effects from relationship lending diminish during the crisis, for the credit access by a maximum of 6 percentage points and up to 50% for loan volumes. Moreover, prices of previous relationship loans increase by up to 25 basis points. These results are consistent with the holding-up argument of Sharpe (1990), and Rajan (1992) (among others).[25]

On the bank level, our results also suggest lower access and granted volumes during the crisis, see Panel B of Table 2. More precisely, Column (1) and (2) reveal that at the peak of the Euribor-OIS spread, borrowing in the overnight segment has become 20 percentage points less likely on average (-10,28*2). This drop corresponds to a reduction in access of up to 47% relative to the average borrowing probability of 42% before Lehman's failure. At the same time, we estimate a drop in the total overnight borrowing amount by 30%. This result is qualitatively similar to our bank-to-bank-level findings (see Column 12 in Table 2 Panel B). Moreover, Column (9) and (10) indicate that the fraction of cross-border loans in banks' overnight interbank borrowing volume declined on average by almost 8 percentage points at the peak of the crisis.

Our results also suggest heterogeneity in wholesale funding. Banks with a larger share of ex-ante cross-border funding relative to their assets size (two standard deviations above mean) pay up to 22 basis points more for overnight interbank borrowing as compared to those with relatively weak cross-border linkages (two standard deviations below mean) during our ex-ante pre-crisis reference period (Column 4 and 5). Moreover, banks with an above-average borrowing concentration (two standard deviations) during the reference period can offset the crisis induced

[25] Yet, relationship lending helps in worse crisis times to provide higher supplied volume of cross-border interbank loans to banks with lower ex-ante equity ratios. The results are not shown in Table 2 to avoid cluttering. Please refer to the online appendix, where we present detailed estimates of all models.

adverse effects on the overall access and volume, but pay up to 30 basis points higher prices (for a 200 basis point increase of the Euribor-OIS spread).

The overall decrease in overnight access of credit extends to the term segment (beyond one week), where the reduction is quantitatively even stronger and volumes drop faster immediately after Lehman's failure, as Panel A of Figure 1 shows. In fact, note the opposite trend in overnight and term lending in the first two weeks after Lehman's failure. In the period thereafter, when term volumes stop declining and rest at 80% below the pre-Lehman mean, also overnight volumes start to decrease.[26] The volumes depicted in Figure 1 refer to newly granted loans and reflect their daily aggregate amounts traded in the overnight and term interbank market.

We also show the results on the term interbank market with controls and fixed effects in Table 3. There is a drop in the likelihood of a term interbank loan by up to 30 percentage points at the peak of the Euribor-OIS spread. Moreover, the decrease in the daily aggregate loan amount reaches a level of up to 80% at the height of the financial crisis. We also find evidence that banks with higher ex-ante cross-border borrowing receive less term interbank loans and pay higher rates for the granted loans, and banks with higher ex-ante concentration in their borrowing pay significantly higher rates (up to 30 basis points) during the crisis than during tranquil times.

In sum, our robust results suggest that the financial crisis implies lower access (with a maximum reduction of 30 percentage points) and lower volume (80%) in term maturity interbank liquidity. We find similar qualitative effects in overnight, but quantitatively smaller, i.e. lower access by about 34% and lower granted volume by 18% (47% and 30%, respectively, at the bank level). In the overnight segment, the interbank liquidity supply restrictions during the crisis particularly worsen for cross-border lending. Furthermore, our results indicate that previous relationships provide overall better access and volumes, but restrict both in crisis times, and increase prices.

4.2 Evidence for the 2010-2012 Sovereign Debt Crisis

For the sovereign period, the results suggest that higher CDS spreads of the country where the bank is headquartered implies less funding access and higher prices for overnight interbank loans, as Panel A of Table 4 shows. The estimated coefficients in Column (2) and (8) imply a decrease of funding access by about 12 percentage points and an increase in spreads by about

[26] For the U.S. federal funds market, Afonso et al. (2011) find that the U.S. money market has been stressed but not frozen immediately after the Lehman's failure.

41 basis points, when the sovereign CDS spread (in logs) of the country where the borrower is headquartered increases from 3.6 (10th percentile) to 5.9 (90th percentile).

This heterogeneity in liquidity conditions stems not only from the time evolution of the overall euro area crisis but also from the heterogeneity across euro area member countries. Figure 2 illustrate the country-group heterogeneity graphically. Supply restrictions to overnight interbank access in crisis times is largely pronounced for Troika-rescued periphery country banks, with an additional reduction of access by 3 percentage points on top of core and large periphery country banks as a response to a unit increase in (log) CDS spreads (Column 4). The price of interbank liquidity increases for all periphery banks, but not for core banks. The increase is of the same magnitude (17 to 21 basis points) for both Troika-rescued and large periphery country banks, as Column (10) shows.

Also in cross-border lending conditions we find important heterogeneity depending on the country where the bank is headquartered. Our results suggest that supply restrictions to cross-border interbank access in crisis times is only binding for Troika-rescued periphery country banks, with an additional reduction of 2.8 percentage points per unit increase in log CDS spreads (Column 6). While for volumes, the compositional effects are similar across core and periphery country banks, for prices, we find the largest effects for cross-border loans for Troika-rescued periphery country banks (marginal effect is 32 basis points higher) followed by large periphery country banks (12 basis points higher). Moreover, borrower banks are about 9 percentage points more likely to get a loan and to receive about 40% more volume from their previous relationship lenders as compared to other lenders (Column 4 and 16). However, if the borrowing bank's sovereign CDS spread deteriorates (i.e. increases by one unit) then previous relationship lender reduce both access to liquidity (by 3.8 percentage points, Column 5 and 6) and granted volumes (by 14%, Column 17 and 18).[27]

Our bank level results, as Panel B of Table 4 suggest, are in line with our bank-to-bank analysis, as they all point to lower funding access, lower volumes granted in general and also for cross-border loans, and higher spreads paid in response to an increase in the borrower's home country risk. The negative effects are strongest for banks from Troika-rescued periphery country banks. This implies that banks' funding restrictions on the bank-to-bank level also show up at the aggregate (borrower) bank level, thus implying that liquidity supply cutbacks – both overall

[27] We also find that small banks from countries with higher CDS spreads have better access (also larger volumes and lower spreads) to cross-border markets from their previous relationship lender. Also similarly to the Lehman period, previous relationship lenders grant larger loan volumes to foreign banks with lower ex-ante equity ratios. In our online appendix, we provide detailed results on these findings.

and cross-border – are not compensated through other counterparties. The loan level analysis is crucial to identify supply of liquidity, as we can control for time-variant unobserved and observed heterogeneity in borrower fundamentals, and even lenders' heterogeneity for the compositional supply effects, such as risk or Eurosystem's liquidity provision. Finally, a borrowing bank with higher ex-ante borrowing concentration strongly benefits in crisis times through lower (volume-weighted) average spreads and higher borrowing volume.

For term interbank loans, our robust results suggest that the crisis also implies lower access and volume in the longer-term maturity interbank liquidity. We graphically illustrate this pattern in Panel B of Figure 1. Economically, an increase in the log of the CDS spread by 1 unit leads to a reduction of the likelihood of term interbank borrowing by 10 percentage points. This amounts to a reduction in access of up to 60 percentage points for borrower from crisis countries (log CDS spread in 90th percentile). We do not find a significant impact of the ex-ante cross-border interbank borrowing on access in the term segment. We also find that banks from the large periphery pay higher rates in the term segment when their country CDS spread increases. Moreover, borrowers with a high ex-ante borrowing concentration relatively have better access to the term interbank loans. Hence, the documented benefits of previous strong relationship lending in the overnight segment also carry over to the riskier term segment.

In total, our results for the sovereign sample yield similar results as those for the Lehman sample, i.e. lower access and volume but higher spreads in both the overnight and term segment. But, we find important heterogeneity depending on the countries where the bank is headquartered. For instance, supply restrictions to cross-border interbank access in crisis times is only binding for Troika-rescued periphery country banks, where the reduction in access is up to 15 percentage points and the increase of prices for newly granted cross-border loans by up to 30 basis points (relative to spreads paid by core country banks). For large periphery, we do not find any significant effect on access but 12 basis points higher spreads relative to core country banks. Differently from the Lehman period, however, we find that previous relationships do not help in crisis times in general, also not to overall cross-border loans. But, our results suggest that small banks from crisis countries have better loan conditions (access, volumes and spreads) for cross-border from their relationship lender.

5 Results on Price Dispersion and Monetary Policy

In this section we present only results on interbank loan prices, in particular related to our empirical analysis of the testable prediction derived from the credit rationing literature, as explained in the section on empirical strategy. In addition, we discuss the effect of the most substantial monetary policy measures, i.e. the announcement of the fixed-rate full allotment policy and the unconventional three-year LTRO on the credit rationing related measure. We first present our results for the Lehman crisis period and move on to the findings for the sovereign crisis period.

5.1 Lehman's Failure and the Fixed-Rate Full Allotment

We analyze the credit rationing related measure that we described in the empirical strategy from three different angles: its heterogeneity across time (different moments of the crises and monetary policy), the heterogeneity across banks (e.g. riskier vs. less riskier), and the heterogeneity across bank pairs (cross-border vs. domestic lending and relationship lending). Figure 3 Panel A illustrates the first two dimensions of heterogeneity. After the Lehman failure, the daily mean of the measure increases by up to 13 basis points (from 2 basis points before the crisis). Moreover, the difference between the 10th percentile and 90th percentile amounts to more than 25 basis points at the peak of the crisis as compared to less than 3 basis points before the crisis. Thus, for some borrowers, the price differences for loans from different lenders during the same morning increase on average by 25 basis points. Recall that we already control for any time-varying lender fixed effects and loan volumes in Figure 3. When we do not control for lender*time (morning) fixed effects and compute the measure based on loans until 6 pm, the average increase of the credit rationing related measure is quantitatively stronger with up to 60 basis points after Lehman.

In Panel A of Table 6, we analyze the effect of the financial crisis and monetary policy on our measure in a regression setting where we can control for borrower fixed effects. The results can be summarized as follows. First, in all specifications our crisis indicator, the Euribor-OIS spread, has a positive and statistically significant effect. Economically, we find that a 100 basis points increase in the Euribor-OIS spread is associated with a higher price dispersion of about 15 basis points, and 30 basis points if we consider a longer post-Lehman period. The effect is stronger (50 basis points) when we construct the measure based on all loans until 6 pm and do not clean for lender*time fixed effects. Second, the announcement of the fixed rate full allotment monetary

policy decreases the price dispersion during the morning on average by about 9 basis points and 24 basis points for the measure based on loans until 6pm, see Column (4) and (6). Figure 3 Panel B visualizes this monetary policy effect while controlling for borrower fixed effects.

We also study the heterogeneity across banks in Panel B of Table 6, where we look closer into the conditional 50th, 75th, and 90th percentile in quantile regressions and analyze whether bank risk – proxied by the average spread paid to the daily mean rate – explains the borrower heterogeneity that is depicted in Figure 3. The results are as follows. Before the Lehman's bankruptcy, there is no effect. In the post-Lehman period, however, riskier borrowers face a significantly larger price variation across all percentiles. In fact, the effect strengthens further throughout the crisis for all percentiles and is quantitatively strongest for the 75th and 90th percentile. Economically, the 90th percentile for a bank with an average spread of two standard deviations above the mean is 20 basis points higher compared to a bank with an average spread two standard deviations below the mean. These results hold even after controlling for the total borrowing amount, the number of lenders, equity ratio and and asset size.

To understand the heterogeneity at the bank-pair level, we also look at the effects of cross-border and relationship lending and analyze the pricing of overnight loans for the same borrower in the same day during four different sub-periods of our Lehman sample that proxy for different moments of the crisis.[28] As explained in the empirical strategy, to control for the same borrower in the same morning and to control for lenders' alternative investment opportunities and liquidity hoarding, all regressions contain borrower*time and lender*time fixed effects, thereby leaving the bank-to-bank variation as the remaining dimension to be explained.

Overall, our findings presented in Panel C of Table 6 reveal that cross-border loans settle on average at higher prices (up to 18 basis points) during the crisis, while before the crisis there is no significant price difference. This result holds also when controlling for higher loan amounts, as cross-border loans have different lending volumes (see appendix). Moreover, on relationship trades, we find that relationship borrowers pay higher prices in the period after Lehman (up to 15 basis points). Yet, on both the extensive margin (loan availability) and volumes, relationship borrower have both better access and receive larger loan amounts compared to spot borrowers, especially during the crisis.

All in all, in the worst moments of the crisis there are substantially different prices for the same borrower in the same morning from different lenders. This price dispersion cannot be

[28] In Tables 6 in the online appendix we also provide the estimates for differences in access and volumes.

explained by lender characteristics (liquidity hording, different outside investment options) and is stronger for the riskier borrowers during the crisis period. Domestic loans trade at lower prices as compared to cross-border loans, but there is no effect previous lending relations on prices. Monetary policy actions, in particular the announcement of the fixed rate full allotment policy, reduce the overall effect by up to 24 basis points.

5.2 Sovereign Debt Crisis and the three-year LTRO

We now present the same results as before but for the sovereign crisis period. Panel A.b of Figure 3 presents the evolution of our credit rationing related measure both for the conditional mean and the upper and lower percentiles. Note again that the figure refers to the data that is cleaned by lender*times fixed effects and loan volumes. The figure illustrates both the co-movement of our price dispersion measure with our crisis variable and that the variation of the credit rationing related measure increases when the sovereign debt crisis deteriorates.

We assess this time dimension in more detail in a regression where we can control for both borrower and time fixed effects. The results from Panel A of Table 7 show that the crisis effect prevails consistently across all specifications. On average, a bank from a country with sovereign CDS spreads (in logs) at the 90% percentile faces an increase in its average borrowing costs (from the minimum rate paid) by about 6.3 basis points more than a similar bank from a country with CDS spreads at the 10% percentile ((5.9803-3.5205)*2.55). The effects are twice as large if we consider the measure based on all loans until 6 pm and do not clean for lender*time fixed effects and volume. A closer look reveals that the large quantitative effects are stemming from banks in the large periphery and in the Troika-rescued countries.

We also study the impact of the announcement of the three-year LTRO on our credit rationing related measure. In all specifications, we find a statistically significant and negative effect, thus suggesting that the unconventional monetary policy announcement reduces on average the price dispersion over the day. In the specifications presented in Column (4) to (7) the announcement effect amounts to a reduction of the measure by up to 20 basis points, depending on bank's country CDS. After controlling for lender*time and (borrower) bank fixed effects, the impact still amounts to up to 11 basis points implying that the three-year LTRO also reduced our price dispersion measure. This effect, however, is especially strong for banks from the large periphery countries (additional 7 basis points).[29] We visualize this monetary policy effect while controlling

[29] Due to few observations involving banks from Troika-rescued periphery countries, we are not able to estimate a separate effect for this country group.

for (borrower) bank fixed effects in Figure 3. It reveals that immediately after the Eurosystem's promise to grant unlimited credit for the period of three years, there is an average decrease of up to 10 basis points corresponding to a more than 85% reduction in our credit rationing related measure.

In analogy to our Lehman sample analysis, we also study the heterogeneity of our price dispersion measure at the (borrower) bank and borrower-lender level. The results for the (borrower) bank heterogeneity analysis are presented in Panel B of Table 7 and consistently show that riskier banks face a significantly higher price dispersion. These effects slightly increase in the course of the sovereign crisis period and hold after controlling for loan amounts and different number of lenders. Furthermore, price dispersion is significantly more pronounced for large periphery and Troika-rescued periphery country banks.

We analyze the effects of cross-border and relationship transactions in Panel C of Table 7, where we study the pricing for the same borrower in the same morning for overnight interbank lending during four different sub-periods that proxy for different crisis moments. Recall that our empirical identification applies lender*time and borrower*time fixed effects to isolate cross border and relationship lending. We find a significant relationship between cross-border trades and pricing, with substantial differences for core versus periphery (either large periphery or Troika-rescued periphery country banks). Effects are strong for the worst moments of the crisis, but are overall not significant before the Greek's recourse to the Eurosystem's financial support and after the three-year LTRO. In the crisis, for core country banks, cross-border loans have lower rates than domestic ones for the same borrower in the same morning. Banks from Troika-rescued periphery countries instead pay on average higher prices (12 basis points) for cross-border loans than core banks, and also for cross-border loans as compared to domestic loans (6 basis points), conditioning on the same borrower bank in the same morning.

In contrast to our Lehman crisis analysis, the results for relationship transactions are not robust against the inclusion of loan amounts. Only during the second half of 2011, we find robust results that lenders with a previous relationships charge lower prices. Our results on both funding access and volumes show that relationship lending grant higher access and volume than lenders without a previous relationship. In the sovereign period, results are robust to the construction of the relationship variable over an almost two year period before the start of the crisis.

All in all, in the worst moments of the crisis – both across the crisis time and across sovereign

risk of the country where the (borrower) bank is headquartered – there are substantial price differences for the same borrower in the same morning from different lenders. The price dispersion is not related to lender*time (morning) characteristics and is even increased for the riskier borrowers in the crisis period. Only for peripheral banks domestic loans offer lower prices as compared to cross-border loans. The announcement of the LTROs reduces the overall price dispersion (maximum reduction of 20 basis points depending on bank's country CDS spread). In sum, the effects are qualitatively similar as in the Lehman case but quantitatively weaker in the sovereign as compared to the Lehman crisis for banks from the core countries. Banks from periphery countries are substantially penalized in our sovereign crisis sample.

6 Conclusion

We analyze the impact of financial crises and monetary policy on the supply of wholesale funding liquidity, and also the compositional supply effects through cross-border lending. For empirical identification, we draw on the proprietary bank-to-bank Euro area interbank dataset for the 2008-2012 period, and also exploit the Lehman and sovereign crises as well as the main Eurosystem non-standard monetary policies on banks.

The robust results imply that crisis implies worse access, volume and spreads for overnight and even more for longer-term maturities. While after Lehman's failure liquidity supply restrictions particularly worsen for cross-border lending, effects are quantitatively stronger in the sovereign debt crisis for banks headquartered in peripheral countries. Moreover, the interbank market – as compared to other credit markets – allows exploiting the price dispersion from different lenders on identical credit contracts, i.e. overnight uncollateralized loans in the same morning for the same borrower. Results on the price dispersion for identical credit con-tracts suggest credit rationing. This price dispersion exhibits large heterogeneity across time depending on the crisis strength, across banks depending on borrower risk, and across bank-pairs depending on cross border and previous relationship lending. Importantly, this heterogeneity decreases when the Eurosystem both promises unlimited access to liquidity at a fixed price and announces the three-year-LTROs.

All in all, the results suggest that information asymmetries problems in interbank markets are important, notably in cross-border lending, and that established credit relationships are an important factor affecting the availability and pricing of wholesale liquidity for banks in crisis periods. These findings have important policy implications. They indicate that a disintegra-

tion of the Euro area money market is persistent, but a reintegration substantially depends on banks' incentives to reestablish cross-border interbank lending relationships. While this happens, monetary policy is of utmost importance to reduce liquidity frictions.

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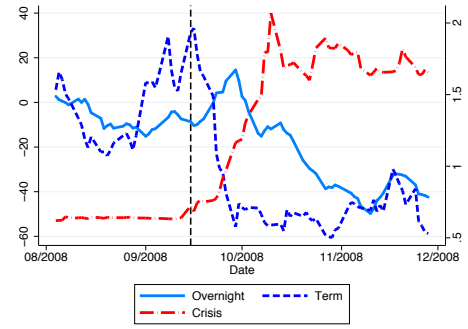
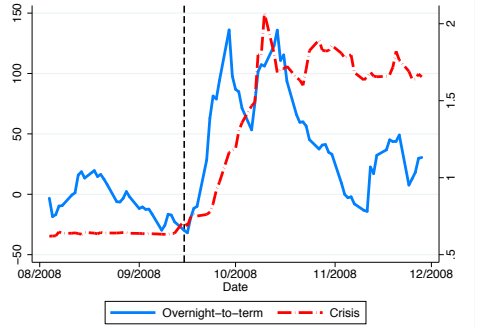
Figures

Figure 1 Panel A:
Overnight vs. term interbank loan volume for the Lehman period



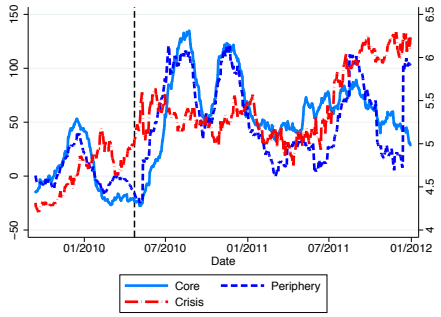
(a) Overnight and term



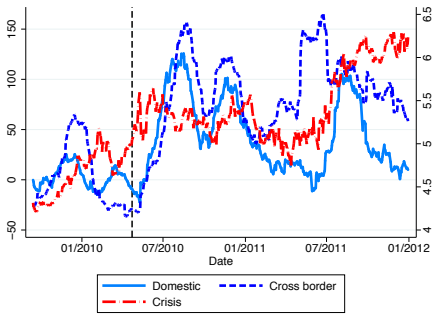
(b) Overnight-to-term ratio

Notes: Panel (a) shows the total daily loan amount borrowed during the Lehman sample for both overnight and term interbank loans from 01 June 2008 – 31 December 2008. Panel (b) depicts the ratio of daily overnight borrowing volume over daily term (maturity larger one week) borrowing volume. All three series are expressed as percentage deviations from the pre-Lehman mean from 01 June 2008 until 12 September 2008 of each respective series. 'Crisis' denotes the three-month Euribor-OIS spread (in % on the right axis). All series are smoothed with a 10-day moving average. The vertical dashed line corresponds to the Lehman failure on 15 September 2008. For further details, see Figure 1, Table 1, and the Table 8.

Figure 1 Panel B:
Overnight vs. term interbank loan volume for the sovereign crisis period



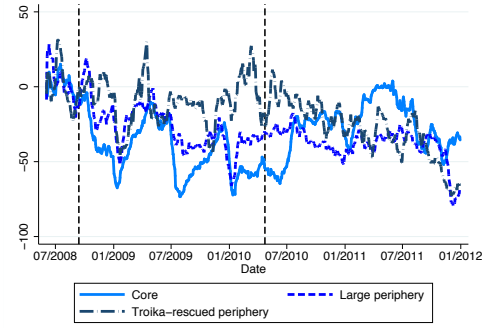
(a) Overnight-to-term ratio Core vs. periphery



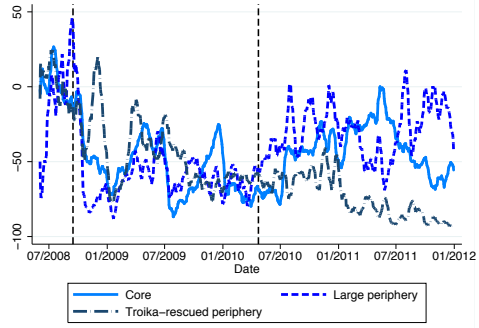
(b) Overnight-to-term ratio Domestic vs. cross-border

Notes: This figure shows the ratio of daily overnight to term interbank lending volumes during the period 07 September 2009 – 31 December 2011 decomposed into core and periphery and domestic and cross-border, respectively. All series are expressed as percentage deviations from the pre-sovereign crisis mean of each series computed on data from 07 September 2009 until 31 December 2009. 'Crisis' denotes the average periphery country CDS spread (in logs on the right axis). We define 'Core' as in Figure 1. 'Periphery' refers to banks headquartered in Italy (IT), Spain (ES) Greece (GR), Ireland (IE), and Portugal (PT). The vertical dashed line corresponds to 23 April 2010, when Greece sought its financial support. All series are smoothed with a 60-day moving average. For further details, see Figure 1, Table 1, and the Table 8.

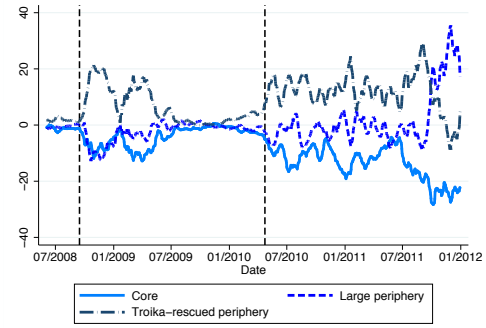
Figure 2:
Domestic vs. cross-border overnight interbank loan conditions by country group



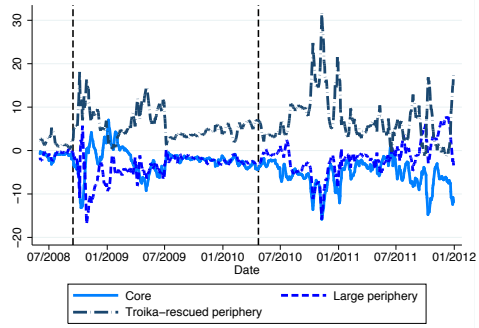
(a) Access: Domestic



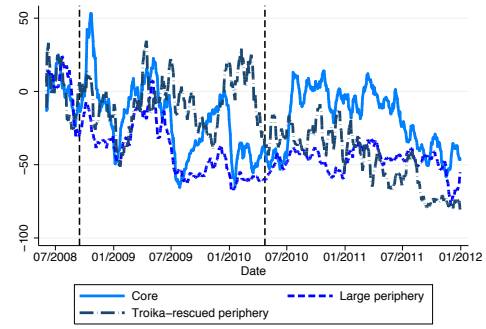
(b) Access: Cross-border



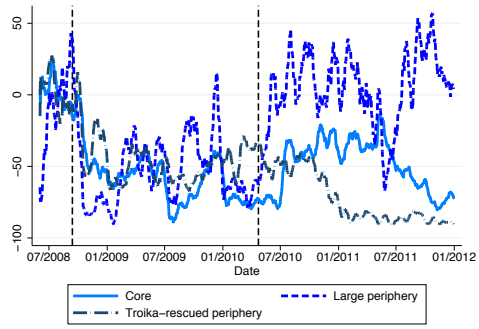
(c) Spread: Domestic



(d) Spread: Cross-border



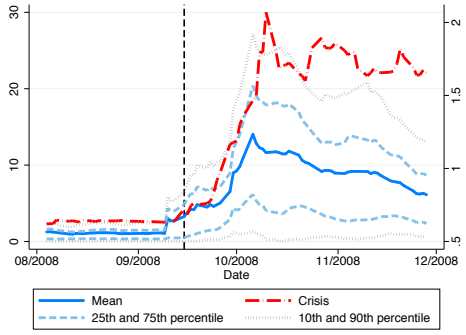
(e) Total amount: Domestic



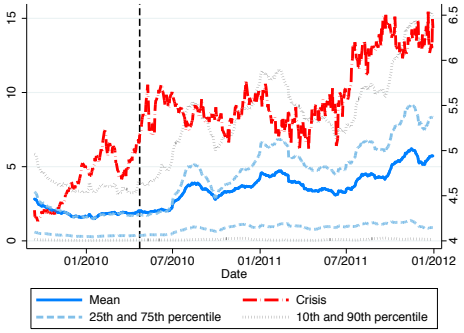
(f) Total amount: Cross-border

Notes: This figure shows our overnight interbank loan data over the entire sample for both domestic and cross-border trades decomposed into country groups. For each group, 'Access' (loan availability) is the daily total number of loans, 'Total amount' is the daily total volume and 'Spread' is the daily mean spread (in basis points) to the (volume-weighted) daily mean rate of all domestic (or cross-border) loans. Volumes and Access are expressed in percentage deviations from the mean of each respective series during the pre-Lehman period from 01 June 2008 until 12 September 2008. We define 'core country banks' as banks from Austria (AT), Germany (DE), Belgium (BE), the Netherlands (NL), France (FR) or Finland (FI). We label banks headquartered in Italy (IT) and Spain (ES) as 'large periphery' country banks. Banks headquartered in countries, which have been rescued by the Troika, i.e. banks in Greece (GR), Ireland (IE), and Portugal (PT), we define as 'Troika-rescued periphery' country banks. The first vertical dashed line corresponds to the Lehman failure on 15 September 2008, and the second vertical dashed line corresponds to 23 April 2010, when Greece sought its financial support. All series are smoothed with a 20-days moving average. For further details, please refer to Section 2, Table 1, and Table 8.

Figure 3 Panel A:
Price dispersion during the morning: bank heterogeneity and crisis



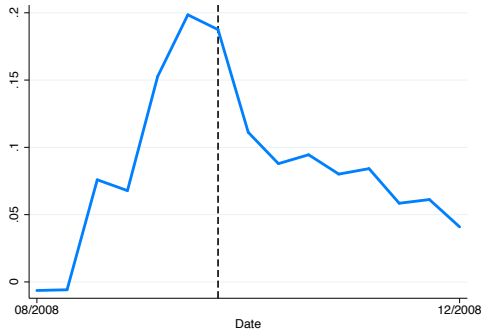
(a) Lehman sample



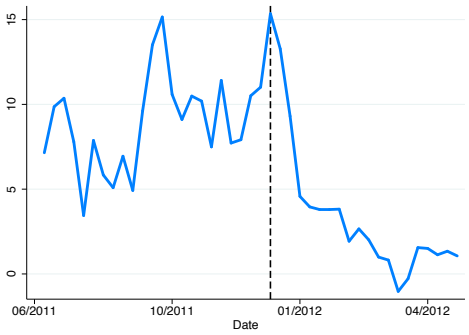
(b) Sovereign crisis sample

Notes: This figure shows the daily mean, 10th, 25th, 75th and 90th percentile of our price dispersion measure for overnight interbank loans granted during the morning (in % on left axis). Panel (a) depicts the measure for the Lehman period where 'Crisis' refers to the three-month Euribor-OIS spread (in % on right axis). Panel (b) depicts the measure for the sovereign crisis where 'Crisis' refers to the average periphery country CDS spread (in logs on right axis). We smooth the series with 10-days and 60-days moving averages for the Lehman and sovereign crisis sample, respectively. For further details, see Figure 1, Table 1, and the Table 8.

Figure 3 Panel B:
Price dispersion over the day: monetary policy effect



(a) Fixed rate full allotment



(b) Three-year LTRO

Notes: This figure shows the estimated weekly time-fixed effect of the linear regression model that regresses 'price dispersion' (in %) on a set of bank fixed effects and week fixed effects to study the monetary policy effect during both the Lehman and sovereign crisis sample. We cover the period from August 2008 until December 2008 and June 2011 until April 2012, respectively. In Panel (a), the vertical line refers to the announcement of the ECB fixed rate full allotment policy on 8 October 2008, while in Panel (b) it denotes the announcement of the Eurosystem's three-year long term refinancing operations on 6 December 2012. For further details, see Panel A of this figure, Figure 1, Table 1, and the Table 8.

Tables

Table 1 Panel A: Summary statistics on overnight interbank loans

Lehman period: 18/08/2008 – 09/11/2008, Daily frequency						
	Mean	Median	Std.	10%	90%	Obs.
$\text{Access}_{i,j,t}$	5.4	0	22.6	0	0	332760
$\text{Spread}_{i,j,t}$	0	-0.42	20.56	-22.86	23.52	13661
$\text{Total amount}_{i,j,t}$	87.04	25	197.6	5	200	13661
$\text{Volume}_{i,j,t}$	3.44	3.22	1.40	1.61	5.30	13661
$\text{Relationship}_{i,j}$	0.09	0	0.28	0	0	13661
$\text{Cross-border}_{i,j}$	0.28	0	0.45	0	1	13661
$\text{Access}_{j,t}$	37.82	0	48.5	0	100	12180
$\text{Spread}_{j,t}$	0	-0.10	20.61	-23.32	25.24	4607
$\text{Total amount}_{j,t}$	351.49	125	621.85	12	900	4607
$\text{Volume}_{j,t}$	4.77	4.83	1.61	2.48	6.80	4607
Borrowing concentration ratio_j	0.36	0.24	0.24	0.14	0.75	4607
Cross-border $\text{borrowing}_{j,t}$	0.05	0.01	0.08	0	0.15	4607
Cross-border borrowing $\text{ratio}_{j,t}$	0.2	0	0.31	0	0.79	4607
Price $\text{dispersion}_{j,t}$ during the morning	11.32	5.17	15.21	0.36	31.68	4527
Crisis_t	1.19	1.17	0.52	0.64	1.82	60
Sovereign period: 01/01/2010 – 31/12/2011, Weekly frequency						
	Mean	Median	Std.	10%	90%	Obs.
$\text{Access}_{i,j,t}$	0.12	0	32.35	0	100	582712
$\text{Spread}_{i,j,t}$	0	-0.84	15.18	-14.63	14.52	60695
$\text{Total amount}_{i,j,t}$	177.21	44	549.18	6	380	60695
$\text{Volume}_{i,j,t}$	3.86	3.78	1.55	1.79	5.94	60695
$\text{Relationship}_{i,j}$	0.09	0	0.28	0	0	60695
$\text{Cross-border}_{i,j}$	0.26	0	0.44	0	1	60695
$\text{Access}_{j,t}$	55.96	100	49.65	0	100	20800
$\text{Spread}_{j,t}$	0	-2.85	17.65	-15.81	19.27	11640
$\text{Total amount}_{j,t}$	997.32	244	2252.08	20	2564.58	11640
$\text{Volume}_{j,t}$	5.42	5.50	1.86	3.00	7.85	11640
Borrowing concentration ratio_j	0.46	0.37	0.27	0.17	0.95	11640
Cross-border $\text{borrowing}_{j,t}$	0.04	0.00	0.09	0	0.10	11640
Cross-border borrowing ratio_j	0.14	0	0.26	0	0.58	11640
Price $\text{dispersion}_{j,t}$ during the morning	6.00	3.48	8.03	0.47	13.99	5617
$\text{Crisis}_{j,t}$	4.79	4.82	0.97	3.52	5.98	11640

Notes: This table shows descriptive statistics on our overnight interbank loan data explained in Section 2. In the upper panel, we present the statistics for the Lehman sample (18 August 2008 – 9 November 2008, daily frequency), whereas the lower panel refers to the sovereign sample (1 January 2010 – 31 December 2011, weekly frequency). 'Access' (loan availability), 'Spread', and 'Volume' (loan conditions) are our dependent variables that we study at the bank-to-bank level in Equation 1 and at the bank level in Equation 2. 'Cross-border borrowing' and 'Price dispersion' are two further dependent variables that we exploit at the bank level in Equation 2 and 3 through 5, respectively. 'Total amount' reflects the loan volume in EUR millions. We provide a definition of all our variables in Table 8.

Table 1 Panel B:
Summary statistics on term interbank loans

Lehman period: 18/08/2008 – 09/11/2008, Daily frequency

	Mean	Median	Std.	10%	90%	Obs.
Term access$_{j,t}$	68.21	100	46.58	0	100	2139
Term spread$_{j,t}$	0.37	-0.12	25.12	-26.03	24.4	1459
Term loan amount$_{j,t}$	89.16	30	173.75	3	220	1459
Term volume$_{j,t}$	3.32	3.40	1.66	1.10	5.39	1459
Term borrowing concentration ratio$_j$	0.30	0.23	0.20	0.10	0.58	1459
Cross-border term borrowing ratio$_j$	0.11	0.03	0.37	0.002	0.20	1459

Sovereign period: 01/01/2010 – 31/12/2011, Weekly frequency

	Mean	Median	Std.	10%	90%	Obs.
Term access$_{j,t}$	404.3	0	49.08	0	100	14744
Term spread$_{j,t}$	4.27	-1.58	27.06	-21.07	41.92	5961
Term loan amount$_{j,t}$	115.14	50	199.57	5	300	5961
Term volume$_{j,t}$	3.76	3.91	1.51	1.61	5.70	5961
Term borrowing concentration ratio$_j$	29.5	22.5	20.97	9.62	60.22	5961
Cross-border term borrowing ratio$_j$	0.04	0.01	0.08	0	0.11	5961

Notes: This table presents the descriptive statistics on term loans, where 'Term' refers to loans with maturity larger than one week. We study the term interbank loan segment at the bank level in Equation 2. For further details, see Section 2.1, Panel A of this table, and Table 8.

Table 2 Panel A:
Overnight credit supply at the bank-to-bank level: Evidence for the Lehman period

	$\text{Access}_{i,j,t}$				$\text{Spread}_{i,j,t}$				$\text{Volume}_{i,j,t}$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Crisis_t	-1.98***				0.21				-0.06			
	(-11.75)				(0.19)				(-1.41)			
$\text{Cross-border}_{i,j}$	-2.35***	-3.55***	-3.55***		1.72**	-0.57	-0.06		1.64***	-0.19***	-0.20***	
	(-8.67)	(-8.86)	(-8.86)		(2.09)	(-0.58)	(-0.06)		(23.30)	(-3.36)	(-3.52)	
Crisis_t*$\text{Cross-border}_{i,j}$			-1.08***	-0.85**			7.17***	6.31***			-0.18***	-0.09***
			(-3.22)	(-2.24)			(4.17)	(4.26)			(-3.28)	(-2.69)
$\text{Relationship}_{i,j}$	1.85**	9.17***	9.17***		6.99***	-0.36	0.19		1.27***	0.42***	0.41***	
	(2.17)	(7.54)	(7.54)		(2.76)	(-0.47)	(0.23)		(10.81)	(7.33)	(6.84)	
Crisis_t*$\text{Relationship}_{i,j}$			-1.49**	-3.09***			10.27***	13.05***			-0.15	-0.28***
			(-2.02)	(-2.68)			(2.61)	(5.47)			(-1.23)	(-4.11)
Time fixed effects	No	Yes	Yes	-	No	Yes	Yes	-	No	Yes	Yes	-
Borrower+Lender fixed effects	No	Yes	Yes	-	No	Yes	Yes	-	No	Yes	Yes	-
Borrower*Time fixed effects	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Lender*Time fixed effects	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Borrower-Lender fixed effects	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Observations	332760	332760	332760	332760	13661	13661	13661	13661	13661	13661	13661	13661

Notes: This table corresponds to Equation 1 and shows the estimated coefficients of the linear regression models for overnight interbank loan availability ('Access') and conditions ('Spread' and 'Volume') during the Lehman sample using bank-to-bank level data, where our observations are at the bank-pair-day level. We use data from 18 August 2008 to 9 November 2008 in our Lehman period estimations. 'Crisis' refers to the three-month Euribor-OIS spread. A constant is included in all specifications if possible but not shown to avoid cluttering. We either include ('Yes') fixed effects, do not ('No') or span by another set of fixed effects ('-'). We cluster robust standard errors at the bank-pair level and present robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1. For further details, see Table 1 and Table 8.

Table 2 Panel B:
Overnight credit supply at the bank level: Evidence for the Lehman period

	$\text{Access}_{j,t}$			$\text{Spread}_{j,t}$		$\text{Volume}_{j,t}$			$\text{Cross-border borrowing}_{j,t}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Crisis_t	-10.28***	-10.28***				-0.16*	-0.15*		-3.90***	-3.84***	
	(-5.88)	(-6.16)				(-1.78)	(-1.69)		(-3.52)	(-3.51)	
Crisis_t*Cross-border borrowing ratio$_j$		6.65	6.15	9.79***	9.01***		0.16	0.14		0.75	-1.56
		(1.45)	(1.47)	(5.87)	(3.62)		(1.16)	(0.76)		(0.38)	(-0.85)
Crisis_t*Borrowing concentration ratio$_j$		24.41***	21.45***	35.68***	32.63***		0.87***	0.97***		5.07	1.23
		(4.47)	(3.68)	(3.18)	(3.05)		(2.91)	(2.97)		(1.63)	(0.40)
Time fixed effects	No	No	Yes	Yes	Yes	No	No	Yes	No	No	Yes
Borrower fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying controls	No	No	Yes	No	Yes	No	No	Yes	No	No	Yes
Observations	12180	12180	12180	4607	4607	4607	4607	4607	4607	4607	4607

Notes: This table refers to Equation 2 and shows the estimated coefficients of the linear regression models for overnight interbank loan availability ('Access') and conditions ('Spread' and 'Volume') during the Lehman sample using bank level data, where our observations are at the borrower-day level. We cover the same period as in Panel A of this table. In the last column of each credit margin (both extensive and intensive), we show our result while controlling for Crisis*Assets and Crisis*Equity ('Time-varying controls'). We cluster robust standard errors at the borrower level. For further details, see the Panel A of this table, Table 1, and Table 8.

Table 3:
Term credit supply at the bank level: Evidence for the Lehman period

	Term access$_{j,t}$			Term spread$_{j,t}$		Term volume$_{j,t}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crisis$_t$	-13.45***	-13.34***				-0.43***	-0.43***	
	(-4.56)	(-4.62)				(-2.69)	(-2.72)	
Crisis$_t$*Cross-border		-9.62***	-6.12	5.43***	5.44		-0.28	-0.37
term borrowing ratio$_j$		(-3.45)	(-1.36)	(2.87)	(1.55)		(-1.57)	(-1.44)
Crisis$_t$*Term borrowing		-0.04	3.03	24.64***	0.18**		0.17	-0.21
concentration ratio$_j$		(-0.00)	(0.23)	(2.84)	(2.02)		(0.32)	(-0.38)
Time fixed effects	No	No	Yes	No	Yes	No	No	Yes
Borrower fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying controls	No	No	Yes	No	Yes	No	No	Yes
Observations	2139	2139	2139	1459	1459	1459	1459	1459

Notes: This table corresponds to Equation 2 shows the estimated coefficients of the linear regression models for term (beyond one week) interbank loan availability ('Term access') and conditions ('Term spread' and 'Term volume') during the Lehman sample using bank level data, where our observations are at the borrower-day level. We cover the same period as in Table 2. We cluster robust standard errors at the borrower level. For further details, see Panel B of Table 1 and 2, and Table 8.

Table 4 Panel A:
Overnight credit supply at the bank-to-bank level: Evidence for the sovereign crisis period

	$Access_{i,j,t}$					$Spread_{i,j,t}$					$Volume_{i,j,t}$				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
$Crisis_{j,t}$	0.17	-3.40***	-2.72***	-1.37**		5.94***	17.90***	18.63***	-2.32***		-0.34***	-0.04	-0.04	-0.05	
	(0.86)	(-7.38)	(-5.50)	(-2.17)		(21.71)	(22.53)	(22.83)	(-2.96)		(-9.03)	(-1.17)	(-1.03)	(-1.04)	
$Crisis_{j,t}$*Large $periphery_j$				0.11					23.50***					0.05	
				(0.24)					(34.68)					(1.18)	
$Crisis_{j,t}$*Troika-rescued $periphery_j$				-2.96***					19.69***					-0.04	
				(-4.37)					(11.65)					(-0.59)	
Cross-$border_{i,j}$	-4.71***	-6.24***	-6.46***	-4.01***		-4.71***	-1.25***	-3.46***	-1.49**		1.24***	-0.09*	-0.10**	-0.18**	
	(-11.46)	(-12.23)	(-12.68)	(-4.96)		(-13.13)	(-4.55)	(-8.86)	(-2.22)		(18.46)	(-1.91)	(-2.22)	(-2.50)	
$Crisis_{j,t}$*Cross-$border_{i,j}$			-1.94***	-0.14	0.46			-8.35***	-2.51***	-20.37***			-0.06	-0.08	-0.07**
			(-5.22)	(-0.26)	(0.85)			(-17.31)	(-3.42)	(-26.35)			(-1.58)	(-1.59)	(-2.14)
$Crisis_{j,t}$*Cross-$border_{i,j}$*Large $periphery_j$				-0.97***	1.51				-0.59***	12.23***				0.05*	0.13
				(-3.43)	(1.63)				(-2.86)	(8.05)				(1.79)	(1.59)
$Crisis_{j,t}$*Cross-$border_{i,j}$*Troika-rescued $periphery_j$				-1.09***	-2.84**				0.66*	31.51***				-0.04	0.02
				(-2.95)	(-2.19)				(1.83)	(12.24)				(-1.42)	(0.12)
$Relationship_{i,j}$	-0.33	8.51***	8.64***	8.64***		0.52	0.20	0.26	0.08		1.01***	0.40***	0.40***	0.40***	
	(-0.41)	(7.16)	(7.35)	(7.36)		(0.88)	(0.61)	(0.76)	(0.25)		(7.59)	(6.86)	(6.86)	(6.81)	
$Crisis_{j,t}$*$Relationship_{i,j}$			-0.82	-0.55	-3.60***			-2.90***	-0.72	-1.41			-0.02	-0.01	-0.14***
			(-1.10)	(-0.73)	(-4.10)			(-4.30)	(-1.26)	(-1.30)			(-0.35)	(-0.18)	(-3.35)
Time fixed effects	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-
Borrower+Lender fixed effects	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-
Borrower*Time fixed effects	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes
Lender*Time fixed effects	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes
Borrower-Lender fixed effects	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes
Observations	582712	582712	582712	582712	582712	60695	60695	60695	60695	60695	60695	60695	60695	60695	60695

Notes: This table refers to Equation 1 and shows the estimated coefficients of the linear regression models for overnight interbank loan availability ('Access') and conditions ('Spread' and 'Volume') during the sovereign crisis sample using bank-to-bank level data, where our observations are at the bank-pair-week level. We use data from 1 January 2010 to 31 December 2011 in our sovereign crisis period estimations. 'Crisis' refers to the sovereign country CDS of the borrower's home country. 'Large periphery' refers to a borrower headquartered in Spain or Italy, whereas "Troika-rescued periphery' denotes borrowers from Greece, Ireland or Portugal. We cluster robust standard errors at the bank-pair level. For further details, see Panel A of Table 1 and 2, and Table 8.

Table 4 Panel B:
Overnight credit supply at the bank level: Evidence for the sovereign crisis period

	$Access_{j,t}$				$Spread_{j,t}$				$Volume_{j,t}$				Cross-border $borrowing_{j,t}$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
$Crisis_{j,t}$	-9.42***	-9.37***	2.46	-9.60***	10.48***	9.81***	-6.93***	7.86***	-0.42***	-0.42***	-0.31**	-0.40***	-2.07	-2.02	0.88	-1.77
	(-3.42)	(-3.43)	(0.81)	(-3.60)	(4.68)	(5.04)	(-3.51)	(4.06)	(-3.23)	(-3.24)	(-2.11)	(-3.22)	(-1.10)	(-1.10)	(0.43)	(-1.09)
$Crisis_{j,t}$*Large $periphery_j$			-3.95				25.91***				0.17				1.59	
			(-1.16)				(12.32)				(1.37)				(1.01)	
$Crisis_{j,t}$*Troika-rescued $periphery_j$			-15.57***				17.89***				-0.23				-4.91*	
			(-3.77)				(7.19)				(-1.15)				(-1.83)	
$Crisis_{j,t}$*Cross-border borrowing $ratio_j$		-6.67	-23.50	-13.56		-21.35**	-7.54	-9.34		-0.41	-0.58	-0.35		-7.12	-5.84	-5.44
		(-0.47)	(-1.28)	(-0.93)		(-2.33)	(-0.76)	(-0.95)		(-1.12)	(-0.98)	(-0.90)		(-1.44)	(-0.87)	(-1.23)
$Crisis_{j,t}$*Cross-border borrowing $ratio_j$*Large $periphery_j$			0.07				-0.00				-0.00				0.11	
			(0.20)				(-0.02)				(-0.00)				(0.89)	
$Crisis_{j,t}$*Cross-border borrowing $ratio_j$*Troika-rescued $periphery_j$			0.08				0.21				0.02				-0.28	
			(0.25)				(1.32)				(1.14)				(-1.30)	
$Crisis_{j,t}$*Borrowing		3.31	3.27	2.92		-17.41***	-5.32	-19.91***		0.33*	0.46**	0.35*		3.15	4.99**	1.86
concentration $ratio_j$		(0.65)	(0.60)	(0.62)		(-3.56)	(-1.00)	(-4.76)		(1.72)	(2.30)	(1.92)		(1.48)	(2.07)	(0.88)
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borrower fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying controls	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Observations	20800	20800	20800	20800	11640	11640	11640	11640	11640	11640	11640	11640	11640	11640	11640	11640

Notes: This table refers to Equation 2 and shows the estimated coefficients of the linear regression models for overnight interbank loan availability ('Access') and conditions ('Spread' and 'Volume') during the sovereign crisis sample using bank level data, where our observations are at (borrower) bank-week level. We cover the same period as in Panel A of this table. In the last column of each credit margin (both extensive and intensive), we show our result while controlling for Crisis*Assets and Crisis*Equity ('Time-varying controls'). We cluster robust standard errors at the bank level. For further details, see Panel A of this table, Table 1, Panel B of Table 2 and Table 8.

Table 5:
Term credit supply at the bank level: Evidence for the sovereign crisis period

	Term access$_{j,t}$				Term spread$_{j,t}$				Term volume$_{j,t}$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Crisis$_{j,t}$	-12.77***	-12.20***	-9.10***	-11.15***	3.42	3.05	-2.74	2.74	-0.39***	-0.42***	-0.22	-0.38***
	(-4.25)	(-4.35)	(-3.41)	(-3.95)	(0.88)	(0.79)	(-1.02)	(0.78)	(-2.82)	(-3.13)	(-1.61)	(-2.99)
Crisis$_{j,t}$*Large periphery$_j$			-2.46				11.92***				-0.04	
			(-0.83)				(4.73)				(-0.26)	
Crisis$_{j,t}$*Troika-rescued$_j$ periphery			-3.55				5.01				-0.34	
			(-0.85)				(0.78)				(-1.65)	
Crisis$_{j,t}$*Cross-border term borrowing ratio$_j$		-0.66***	-0.68***	-0.69***		0.12	0.09	0.08		0.03	0.03	0.03
		(-7.78)	(-8.09)	(-8.08)		(0.30)	(0.35)	(0.19)		(1.60)	(1.44)	(1.36)
Crisis$_{j,t}$*Cross-border term borrowing ratio$_j$*Large periphery$_j$			0.34				-0.32*				0.04*	
			(1.04)				(-1.86)				(1.94)	
Crisis$_{j,t}$*Cross-border term borrowing ratio$_j$*Troika-rescued periphery$_j$			-1.40***				-0.10				-0.05**	
			(-5.64)				(-0.20)				(-2.07)	
Crisis$_{j,t}$*Term borrowing concentration ratio$_j$		18.74***	18.06***	18.96***		-3.32	-4.62	-3.69		-0.27	-0.30	-0.17
		(3.33)	(3.18)	(3.19)		(-0.43)	(-0.68)	(-0.48)		(-0.99)	(-1.08)	(-0.66)
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borrower fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying controls	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Observations	14744	14744	14744	14744	5961	5961	5961	5961	5961	5961	5961	5961

Notes: This table corrsponds to Equation 2 and shows the estimated coefficients of the linear regression models for term interbank loan availability ('Term access') and conditions ('Term spread' and 'Term volume') during the sovereign crisis sample using bank level data, where our observations are at borrower-week level. We cover the same period as in Table 4. We cluster robust standard errors at the borrower level. For further details, see Panel B of table, Table 1 and 4 and Table 8.

Table 6 Panel A:
Time variation of price dispersion: Evidence on crisis and monetary policy for the Lehman period

	Price dispersion$_{j,t}$ over the day		Price dispersion$_{j,t}$ during the morning			
	(1)	(2)	(3)	(4)	(5)	(6)
Crisis$_t$	24.81***	24.75***	7.31***	7.31***	14.03***	14.07***
	(15.95)	(16.37)	(11.65)	(12.25)	(15.67)	(15.73)
Full Allotment$_t$	-23.98***	-23.84***			-9.43***	-9.44***
	(-11.60)	(-11.88)			(-10.32)	(-10.08)
Borrower fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Time fixed effects	No	No	Yes	Yes	Yes	Yes
Loan amount controls	No	No	Yes	Yes	Yes	Yes
Time-varying controls	No	Yes	No	Yes	No	Yes
Observations	4527	4527	2553	2553	3299	3299

Notes: This table corresponds to Equation 3 and shows the estimated coefficients of the linear regression models that study the crisis and monetary policy effect on price dispersion using overnight interbank loan data at the bank level for the Lehman sample. In column (3) and (4), we use the same period as in Table 2. We extend the sample to 12 weeks after the Lehman's failure in column (1), (2), (5), and (6) to assess the monetary policy effect. We measure 'Crisis' as the three-month Euribor-OIS spread. 'Full Allotment' is a binary variable that accounts for the announcement of the ECB fixed rate full allotment policy on 8 October 2008. 'Loan amount controls' indicates whether we control for loan amounts in the construction of 'Price dispersion'. 'Time-varying controls' refer to 'Crisis*Cross-border borrowing ratio' and 'Crisis*Borrowing concentration ratio' (in column 2, 4 and 6) as well as 'LTRO*Cross-border borrowing ratio' and 'LTRO*Borrowing concentration ratio' in column 2. We cluster robust standard errors at the borrower level. For further details, see Panel B of Table 2 and Table 8.

Table 6 Panel B:
Bank heterogeneity of price dispersion: Evidence on borrower risk for the Lehman period

	Percentiles of Price dispersion$_{j,t}$ during the morning											
	Last 2 weeks before Lehman			First 2 weeks after Lehman			3rd to 4th week after Lehman			5th to 8th week after Lehman		
Percentile	p50%	p75%	p90%	p50%	p75%	p90%	p50%	p75%	p90%	p50%	p75%	p90%
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Borrower risk$_{j,t}$	6.30	6.02	1.65	4.10*	8.55**	4.17	3.15	8.29***	13.57***	10.60***	17.46***	26.34***
	(1.34)	(1.21)	(0.22)	(1.91)	(2.07)	(0.82)	(0.82)	(3.23)	(3.65)	(4.71)	(6.47)	(7.20)
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Times fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Loan amount controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borrower controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	920	920	920	526	526	526	416	416	416	691	691	691

Notes: This table relates to Equation 4 and shows the estimated coefficients of the quantile regressions that study the effect of borrower risk on price dispersion using overnight interbank loan data at the bank level for the Lehman sample. 'Borrower risk' refers to the average spread paid by each borrower on the previous day as a proxy for borrower risk. 'Borrower controls' refer to 'Assets', 'Equity', 'Number of lenders', 'Volume', 'Cross-border borrowing ratio' and 'Borrowing concentration ratio'. We cluster robust standard errors at the borrower level. For more details, see Panel A of this table and Table 8.

Table 6 Panel C:
Bank-pair heterogeneity of price dispersion: Evidence on cross-border and relationship for the Lehman period

	$\text{Spread}_{i,j,t}$ during the morning							
	Last 2 weeks before Lehman		First 2 weeks after Lehman		3rd to 4th week after Lehman		5th to 8th week after Lehman	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\text{Cross-border}_{i,j}$	0.37	0.73	9.77***	7.65***	24.23***	16.49	21.84***	18.47***
	(0.63)	(1.16)	(5.39)	(4.08)	(2.68)	(1.57)	(5.58)	(4.56)
$\text{Relationship}_{i,j}$	-0.65**	-0.37	4.07***	2.63**	13.04***	6.67*	24.83***	14.66***
	(-2.45)	(-1.33)	(3.37)	(2.15)	(3.35)	(1.79)	(5.30)	(3.02)
$\text{Loan amount}_{i,j,t}$		-0.33**		1.92***		6.79***		7.59***
		(-2.49)		(5.39)		(5.30)		(4.93)
Borrower*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2234	2234	1506	1506	1327	1327	1856	1856

Notes: This table corresponds to Equation 5 and shows the estimated coefficients of the linear regressions models for overnight interbank loan pricing using bank-to-bank level data for the Lehman sample, where our observations are at bank-pair-day level. 'Time-varying controls' includes 'Cross-border*Assets', 'Cross-border*Equity', 'Relationship*Assets' and 'Relationship*Equity'. We cluster robust standard errors at the bank-pair level. For further details, see Panel A and B of this table and Table 8.

Table 7 Panel A:
Time variation of price dispersion: Evidence on crisis and monetary policy for the sovereign crisis period

	Price dispersion$_{j,t}$ over the day			Price dispersion$_{j,t}$ during the morning			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crisis$_{j,t}$	4.91***	4.68***	-1.75***	2.55***	2.48***	-0.79**	-0.14
	(5.65)	(5.57)	(-3.00)	(6.60)	(6.63)	(-1.98)	(-0.40)
Crisis$_{j,t}$*Large periphery$_j$			8.12***			4.07***	4.43***
			(7.84)			(9.16)	(8.42)
Crisis$_{j,t}$*Troika-rescued periphery$_j$			14.57***			2.93***	3.45***
			(5.51)			(4.67)	(7.58)
LTRO$_t$	-7.57***	-10.78***	-19.82***				-11.25***
	(-3.42)	(-3.00)	(-4.81)				(-3.03)
LTRO$_t$*Large periphery$_j$			-8.82***				-6.59***
			(-4.58)				(-4.89)
LTRO$_t$*Crisis$_{j,t}$	0.67	1.29*	4.06***				2.44***
	(1.39)	(1.79)	(4.26)				(2.88)
Time fixed effects	No	No	No	Yes	Yes	Yes	No
Borrower fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Time fixed effects	No	No	No	Yes	Yes	Yes	Yes
Loan amount controls	No	No	No	Yes	Yes	Yes	Yes
Time-varying controls	No	Yes	Yes	No	Yes	Yes	Yes
Observations	18130	18130	18130	18682	18682	18682	12990

Notes: This table corresponds to Equation 3 and shows the estimated coefficients of the linear regression models that study the crisis and monetary policy effect on price dispersion using overnight interbank loan data at the bank level for the sovereign crisis sample. In column (4), (5), and (6) we use the same period as in Table 4. We extend the sample to end of April 2012 in column (1), (2), (3), and (7) to assess the monetary policy effect. We measure 'Crisis' as the log sovereign CDS spread of the borrower's home country. 'LTRO' represents a dummy variable and measure the announcement of the Eurosystem's three-year long term refinancing operations on 6 December 2012. 'Loan amount controls' indicate whether we control for loan amounts in the construction of 'Price dispersion'. 'Time-varying controls' refer to 'Crisis*Cross-border borrowing ratio' and 'Crisis*Borrowing concentration ratio' (in column 5); 'Crisis*Cross-border borrowing ratio', 'Crisis*Borrowing concentration ratio', 'LTRO*Cross-border borrowing ratio' and 'LTRO*Borrowing concentration ratio' (column 2), and, additionally, 'Crisis*Cross-border borrowing ratio', and 'LTRO*Cross-border borrowing ratio' in interaction with borrower country group dummies in Column (3) and (7). We cluster robust standard errors at the borrower level. For further details, see Panel B of Table 4 and Table 8.

Table 7 Panel B:
Bank heterogeneity of price dispersion: Evidence on borrower risk for the sovereign crisis period

	Percentiles of Price dispersion$_{j,t}$ during the morning											
	01/2010 - 04/2010			05/2010-06/2011			07/2011-12/2011			01/2012-04/2012		
Percentile	50%	75%	90%	50%	75%	90%	50%	75%	90%	50%	75%	90%
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Borrower risk$_{j,t}$	4.60***	10.91***	5.33	8.49***	12.77***	15.82***	7.29***	10.66***	12.73***	10.43***	15.02***	24.11***
	(2.60)	(4.64)	(1.01)	(14.42)	(19.93)	(11.18)	(12.20)	(11.05)	(6.89)	(6.03)	(6.31)	(6.34)
Large periphery$_j$	0.66***	0.73***	1.29**	0.82***	0.85***	0.89***	2.05***	2.86***	4.71***	0.86***	1.01***	1.17**
	(7.70)	(4.74)	(2.33)	(13.06)	(7.94)	(3.62)	(12.00)	(8.60)	(6.10)	(4.35)	(3.83)	(2.00)
Troika-rescued periphery$_j$	0.22	0.67	8.72***	1.41***	4.48***	8.57***	-1.35	5.06*	13.95***			
	(1.37)	(1.29)	(3.43)	(7.08)	(6.21)	(10.56)	(-1.31)	(1.67)	(3.60)			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Loan amount controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borrower controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1805	1805	1805	12907	12907	12907	3970	3970	3970	918	918	918

Notes: This table relates to Equation 4 and shows the estimated coefficients of the quantile regressions that study the effect of borrower risk on price dispersion using overnight interbank loan data at the bank level for the sovereign crisis sample. 'Borrower controls' refer to 'Assets', 'Equity', 'Number of lenders', 'Volume', 'Cross-border borrowing ratio' and 'Borrowing concentration ratio'. We cluster robust standard errors at the borrower level. For further details, see Panel A of this table and Table 8.

Table 7 Panel C:
Bank-pair heterogeneity of price dispersion: Evidence on cross-border and relationship for the sovereign crisis period

	Spread$_{i,j,t}$ during the morning							
	01/2010 - 04/2010		05/2010-06/2011		07/2011-12/2011		01/2012-04/2012	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cross-border$_{i,j}$	0.83	0.07	-3.00***	-3.06***	-28.56***	-30.36***	-3.99	-4.02
	(0.68)	(0.05)	(-3.09)	(-3.29)	(-5.68)	(-6.06)	(-1.51)	(-1.57)
Cross-border$_{i,j}$*Large periphery$_j$	-0.83	-0.56	-0.31	0.06	8.11	11.13*	2.73	2.63
	(-0.65)	(-0.43)	(-0.25)	(0.05)	(1.35)	(1.90)	(0.39)	(0.39)
Cross-border$_{i,j}$*Troika-rescued periphery$_j$	-4.29**	-4.12**	8.90***	9.42***				
	(-2.45)	(-2.42)	(4.22)	(4.53)				
Relationship$_{i,j}$	-0.37	-0.82**	1.13	1.65**	-7.62***	-5.44**	-0.67	-0.38
	(-1.21)	(-2.09)	(1.64)	(2.50)	(-3.06)	(-2.28)	(-1.02)	(-0.60)
Loan amount$_{i,j,t}$		0.45***		-0.64***		-2.37***		-0.49**
		(2.89)		(-3.20)		(-4.22)		(-2.56)
Borrower*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1879	1879	12663	12663	3901	3901	1390	1390

Notes: This table corresponds to Equation 5 and shows the estimated coefficients of the linear regressions models for overnight interbank loan pricing using bank-to-bank level data for the sovereign crisis sample, where our observations are at bank-pair-week level. 'Time-varying controls' includes 'Cross-border*Assets', 'Cross-border*Equity', 'Relationship*Assets' and 'Relationship*Equity'. We cluster robust standard errors at the bank-pair level. For further details, see Panel A and B of this table and Table 8.

Table 8 Panel A:
Definition of dependent variables

Variable	Definition
$\text{Access}_{i,j,t}$	Binary variable that equals the value 100 if lender bank i grants at least one overnight interbank loan to borrower bank j during day (or week) t, and zero otherwise.
$\text{Spread}_{i,j,t}$	Difference (in basis points) between the interest rate that borrower j pays to lender i for an overnight interbank loan during day (or week) t and the volume-weighted average rate of all granted loans during the same day (or week).
$\text{Volume}_{i,j,t}$	Measures the logarithm of the total overnight interbank loan amount (in EUR million) that lender i provides to borrower j during day (or week) t.
$\text{Access}_{j,t}$	Binary variable that equals the value 100 if borrower j received at least one overnight interbank loan during day (or week) t, and zero otherwise.
$\text{Spread}_{j,t}$	Difference (in basis points) between the volume-weighted interest rate that borrower j pays for its overnight interbank loans during day (or week) t and the volume-weighted average rate of all overnight interbank loans granted during the same day (or week).
$\text{Volume}_{j,t}$	Measures the logarithm of the total overnight interbank loan amount (in EUR million) that borrower j borrows during day (or week) t.
Cross-border $\text{borrowing}_{j,t}$	Measures the total overnight interbank loan amount that borrower j borrows cross border during day (or week) t as a share of its total overnight interbank loan amounts borrowed during the same day (or week).
Term $\text{access}_{j,t}$	Binary variable that equals the value 100 if borrower j received at least one term interbank loan during day (or week) t, and zero otherwise. 'Term' refers to loans with maturity higher than one week.
Term $\text{spread}_{j,t}$	Difference (in basis points) between the interest rate that borrower j pays for a term interbank loan during the day (or week) t and the volume-weighted average interest rate in the respective maturity bucket. 'Term spread' measures the average of these spreads across the different maturity buckets that borrower j pays for all its term interbank loans during the day (or week) t.
Term $\text{volume}_{j,t}$	Measures the logarithm of total term interbank loan amount (in EUR million) that borrower j borrows during day (or week) t.
Price $\text{dispersion}_{j,t}$	Difference (in basis points) between the volume-weighted mean absolute deviation of interests rates that borrower j pays for all its overnight interbank loans during the same morning (or day) and the minimum rate that she pays during the same morning (or day). For the morning (or day) bin, we use all trades conducted until noon (or 6pm).

Notes: This table provides the definitions of our dependent variables that we use in our empirical strategy explained in Section 3. In Section 2.1, we explain the data that we use to compute these variables. 'Access' denotes the extensive margin and 'Spread' and 'Volume' refer to the intensive margin of credit, i.e. $\text{Access}_{j,t}$=1. To construct 'Term spread', we define four different term buckets. The first one contains all loans with maturity larger than one week and less than 31 days. The second bucket includes all loans with maturity larger than 31 days but less or equal than 60 days. The third bucket contains loans with maturity larger than 60 days but less than 91 days. The fourth classification covers the longest-dated loans, with maturity larger than 90 days.

Table 8 Panel B:
Definition of independent variables

Variable name	Definition
Crisis_t	Denotes the three-month Euribor-OIS spread (in %) on any given day t.
$\text{Crisis}_{j,t}$	Denotes the five-day moving average of the logarithm of the five-year sovereign CDS (in basis points) on any given week t of that country, where the borrower j is headquartered.
Full Allotment_t	Binary variable that equals the value one as of the Eurosystem's announcement of the fixed rate full allotment policy on 8 October 2008, and zero otherwise.
LTRO_t	Binary variable that equals the value one as of the ECB's announcement of the first 3-year long term refinancing operations on 8 December 2011, and zero otherwise.
Large periphery_j	Binary variable that equals the value one for any borrower j headquartered in Italy or Spain, and zero otherwise.
$\text{Troika-rescued periphery}_j$	Binary variable that equals the value one for any borrower j headquartered in Greece, Ireland or Portugal, and zero otherwise.
$\text{Cross-border}_{i,j}$	Binary variable that equals the value one when lender i and borrower j are headquartered in different countries, and zero otherwise.
$\text{Cross-border borrowing ratio}_j$	Measures the total overnight interbank loan amount that borrower j borrows cross-border during a reference period as a share of its asset size. We use borrower j's lagged asset size.
$\text{Relationship}_{i,j}$	Binary variable that equals the value one for any lender i from which borrower j obtains its largest share of total overnight interbank loans during the reference period, and zero otherwise.
$\text{Borrowing concentration ratio}_j$	Measures the total overnight interbank loan amount that borrower j obtains from its most important (in terms of loan amount) lender over a reference period as a share of its total overnight interbank borrowing during the same reference period.
$\text{Term cross-border borrowing ratio}_j$	Measures the total term interbank loan amount that borrower j borrows cross-border during a reference period as a share of its asset size. We use borrower j's lagged asset size.
$\text{Term borrowing concentration ratio}_j$	Measures the total term interbank loan amount that borrower j obtains from its most important (in terms of loan amount) lender over a reference period as a share of its total term interbank borrowing during the same reference period.

Notes: This table provides the definitions of our independent variables that we use in our empirical strategy to study the extensive and intensive margin of credit and price dispersion as explained in Section 3. For 'Cross-border borrowing ratio$_j$', 'Borrowing concentration ratio$_j$', 'Term cross-border borrowing ratio$_j$', and 'Term borrowing concentration ratio$_j$', we use the reference period from 1 June 2008 to 9 August 2008 for the Lehman period, and from 7 September 2009 to 31 December 2009 for the sovereign crisis sample. For further details, see Panel A of this table.

Brief Discussion of the Target2 Data

In contrast to the U.S. Fedwire Funds data, the Target2 dataset has a major advantage as it reflects information on both the direct and indirect participants of the Target2 system. That is, we can exactly distinguish between those parties that actually initiate and receive the payments from those who are in charge of settling these flow orders.

To see why this matters, suppose 'Bank A' and 'Bank E' are both indirect participants. Assume further that 'Bank A' (actual originator or lender) provides a loan to 'Bank E' (actual beneficiary or borrower), that is settled via the two direct Target2 participants 'Bank B' and 'Bank C' with which Bank A and E have their accounts with, respectively. If we only consider the two involved settling banks, we may misidentify this as a loan between the two direct contributors 'Bank B' and 'Bank C' while in fact 'Bank A' and 'Bank E' are the actual parties associated with the interbank transaction. Most of the studies that rely on U.S. Fedwire Funds data suffer from this issue. If we followed the same approach, we would have an error rate of approximately 43% of misidentified deposits thereby exposing our estimations much more to the problem of false positives as explained in Armantier and Copeland (2012).

Also, matching the additional information on the actual involved parties *after* this first identification step will (at a minimum) increase the type-1 error that accounts for a proxy of 20% wrongly identified loans.[30] The identification may even become worse in the following two cases. First, suppose that for the same loan between 'Bank A' and 'Bank E', the above described direct participants are used for the front leg only. For the returning leg of the loan, it might be that 'Bank E' debits funds from its account held with 'Bank D' to credit the loan amount to the bank account of 'Bank A' held with 'Bank B'. Using the data on the direct participant banks only will ignore these transactions completely.

Second, suppose 'Bank B' and 'Bank C' are large financial institutions that are responsible for the settlement of a substantial proportion of interbank payments in the euro area. In other words, 'Bank B' and 'Bank C' settle many different payment legs on a daily basis, which increases the chance of mismatching the transaction legs even further. Most importantly, however, we consider the information on the actual counterparties of a loan – as opposed to the settling parties only, wherever they differ – to be crucial for our study on established credit relationships and any further decomposition such as domestic vs cross-border and core vs. periphery.

[30] These are preliminary estimates and final validation is still ongoing.

Therefore, we use the dataset with the information on the actual originator and beneficiary of any transaction to run the Furfine-adjusted (Aciero et al., 2013) algorithm. In a second step, we aggregate individual institutions at the level of consolidated banking groups, incorporating yearly information on bank mergers and acquisitions obtained from Swift. Therefore, based on the frequency and size of the identified loans, we analyze the money market transactions between any two (consolidated) credit institutions that have been involved (at least once) in a credit transfer during the period from June 2008 until end of April 2012.[31]

[31] Euro-wide data before July 2008 is not available, as payments systems were maintained on a national central bank level only. We do not use data after mid 2012, as the deposit rate cut to 0% on July 2012 may hinder the precision of our algorithm. We leave the period after mid 2012 therefore for future research.