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

Puriya Abbassi[1], Falk Bräuning[2], Falko Fecht[3] and José-Luis Peydró[4]

[1]Deutsche Bundesbank

[2]VU University Amsterdam and Tinbergen Institute

[3]Frankfurt School of Finance and Management

[4]ICREA-Universitat Pompeu Fabra, Cass Business School, CREI, Barcelona GSE and CEPR

This version: May 2015

Abstract

We analyze funding liquidity supply, including cross-border. For identification, we exploit the proprietary TARGET2 dataset, the Lehman and sovereign crisis shocks, and the Eurosystem non-standard monetary policy changes. The crisis shocks induce a tightening of the liquidity supplied, especially for cross-border lending, with stronger impact in the sovereign crisis for banks from periphery. Moreover, the interbank market – unlike other markets – allows identifying price dispersion from different lenders on identical contracts (overnight-uncollateralized loans in the same morning for the same borrower). This price dispersion increases massively with the crisis, especially for riskier lending, and decreases with the expansionary monetary policies.

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

*We would like to thank Franklin Allen, Markus Brunnermeier, Adam Copeland, Martin Diehl, Darrel Duffie, Co-Pierre Georg, Ralph de Haas, Heinz Herrmann, Emanuel Fahri, Daniel Ferreira, Xavier Freixas, Jordi Gali, Matti Hellqvist, Christoph Memmel, Alexander Müller, Jean-Charles Rochet, Harald Uhlig and seminar participants at the Deutsche Bundesbank, at the European Central Bank, at the Barcelona GSE Summer Forum on Asset Prices and the Business Cycle, at the LSE conference on Economic Networks and Finance, at Tilburg University, Maastricht University, and University of Zurich. Falk Bräuning thanks the Netherlands Organisation for Scientific Research (NWO) for financial support. Puriya Abbassi is member of one of the user groups with access to Target2 data in accordance with Article 1(2) of Decision ECB/2010/9 of July 29, 2010 on access to and use of certain Target2 data. The Deutsche Bundesbank and the PSSC have checked the paper against the rules for guaranteeing the confidentiality of transaction-level data imposed by the PSSC pursuant to Article 1(4) of the above mentioned issue. José-Luis Peydró acknowledges financial support from project ECO2012-32434 of the Spanish Ministry of Economics and Competitiveness. The views expressed in the paper are solely those of the authors and do not necessarily represent the views of the Eurosystem or any of its staff. Emails: puriya.abbassi@bundesbank.de (Puriya Abbassi), f.brauning@vu.nl (Falk Bräuning), f.fecht@fs.de (Falko Fecht), jose.peydro@upf.edu (José-Luis Peydró).

1 Introduction

The global financial crisis that started with the Lehman Brothers failure in September 2008 and intensified, especially in the euro area, with the sovereign debt crisis after April 2010 was largely centered on dry-ups in wholesale funding liquidity, in stark contrast to historical systemic crises where the runs were mainly by retail depositors. Importantly, there has been a geographical fragmentation of liquidity in global markets, notably around the sovereign debt crisis, partially unwinding 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. In this paper, 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.

Despite the utmost importance of this question for academia and policy, empirical analysis is scarce, mainly due to the relative lack of comprehensive micro-datasets since wholesale transactions are mostly over-the-counter. In this paper, we overcome this hurdle by using a new (lender-borrower) *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 strengths of this data are fourfold. First, compared 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 a dataset comprising all bank-to-bank payments settled via the euro area large-value payment system Target2. In contrast to U.S. payment system data, our database provides us with identifiers for interbank credit transactions and the ultimate borrower and lender banks involved in the transaction, which are crucial for identifying various testable predictions from the literature on wholesale funding liquidity. Third, apart from the global Lehman shock, the euro area was exposed to substantial risks associated with various countries' sovereign debt, which gives our data larger cross-border and time 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, directed almost exclusively at the banking sector.

To identify the supply of interbank liquidity while controlling for borrower-bank fundamentals that proxy for higher counterparty risk (Afonso, Kovner, and Schoar, 2011), we use (lender-borrower) bank-to-bank loan level data and control for time-varying observed and unobserved

borrower heterogeneity with borrower*time fixed effects. Moreover, we control in some specifications for lending (opportunity) costs and liquidity hoarding (Allen, Carletti, and Gale, 2009, Diamond and Rajan, 2009) by adding, in some specifications, lender*time fixed effects. In this way we further isolate the supply of cross-border, where the variation is at the bank-to-bank level. Furthermore, to estimate time-varying effects of cross-border lending, we add lender*borrower fixed effects to account for the overall effects of cross-border (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 over the course of the crisis (also as compared to normal times) and before and after the main non-standard monetary policy shocks (i.e. the fixed-rate full allotment and three-year LTRO). But we also study the supply of interbank liquidity without these fixed effects. We analyze both the extensive and intensive margin of lending, both loan volumes and spreads, and both the overnight and the longer-term (over one week and up to one year) maturities.

Importantly, unlike with other credit markets, we observe in the interbank market multiple financial contracts that are identical:[1] unsecured overnight loans to the same borrower during the same morning (or same day) from different lenders. Therefore, we also 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 time-varying lending costs, liquidity hoarding from different lenders, the volume each lender gives to a particular borrower, and the number of counterparties. We also analyze whether domestic (versus cross-border) occurs at lower or higher 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 having higher demand as she is also borrowing at a higher interest rate in the same morning from another lender.

During the Lehman crisis, the robust results suggest that the crisis implies lower access (with a maximum reduction of about 25%) and volumes in term maturity interbank liquidity (around 61% of reduction). This strong reduction was substituted partially with higher overnight interbank volumes in the initial two weeks after the Lehman failure, which would imply that,

[1]Throughout the paper, we use the expression 'identical contract' and 'identical loan' interchangeably, where 'identical' refers to an overnight loan to the same borrower during the same morning (or same day).

analyzing only the overnight market, one would conclude that the interbank market is working. However, looking beyond the first two weeks after the Lehman failure, the effects in the overnight segment are similar to the term segment: at the bank-to-bank (loan) level, the crisis implies at its worst moment a reduction of up to 47% in access to liquidity as compared to pre-Lehman. This funding cut-off cannot be compensated at the bank level: a borrowing bank faces, at the same time, a reduction of roughly 35% in access and 23% in volumes. Moreover, the interbank liquidity supply restrictions during the crisis on access, volumes and spreads particularly worsen for cross-border lending (up to 12% lower volumes and 9 basis points higher prices compared to domestic loans).

In the sovereign debt crisis, we find similar results regarding worse access, volumes, and spreads in both the overnight and term interbank segments, 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 are only binding for borrowers from Troika-rescued periphery countries (i.e. Portugal, Ireland and Greece, which were rescued by an IMF-EU-ECB consortium, hereinafter referred to as the Troika), with a reduction of up to 99% at the worst moment of the crisis. Moreover, for the granted cross-border loans, spreads paid by banks headquartered in these countries increase by 31 basis points relative to core country banks. For the large periphery banks headquartered in Italy and Spain, the crisis-induced effect on access is not different from core country banks, but spreads increase by 12 basis points as compared to spreads paid by core country banks. Overall, for all margins and in both crisis periods, effects are quantitatively substantially stronger for interbank access and volumes than for prices.

Regarding our measure related to price dispersion for identical contracts, we find that differences in prices from different lenders for overnight unsecured loans to the same borrower in the same day or morning increase significantly in crisis times, even after controlling for lender*time fixed effects and loan amounts from each lender. On the worst day of the Lehman crisis, 10% of all banks face an average price dispersion of 80 basis points during the day (33 basis points during the morning). We also find strong borrower heterogeneity, in particular riskier banks face larger price dispersion during the same morning. Furthermore, for the identical loan contracts, lenders from the same country offer lower prices as compared to foreigners. None of these effects are significant in the period prior to the Lehman failure. Moreover, the crisis-induced price dispersion during the day considerably decreases by up to 47 basis points after the Eurosystem

promises unlimited access to central bank reserves at a pre-announced fixed price on October 8, 2008.

Finally, the results related to price dispersion in the sovereign crisis are similar to the Lehman period, yet quantitatively at a smaller scale. The quantitative effects, however, are significantly stronger for banks headquartered in the large periphery and in the Troika-rescued periphery as compared to banks headquartered in core countries. Importantly, the heterogeneity decreases after the Eurosystem implements, in December 2011, the first three-year LTRO, i.e. all desired liquidity at a pre-announced fixed rate for a period of three years against an eligible pool of collateral. These mitigating effects are strongest for banks from large periphery countries (reduction of 21 basis points). The mitigating impact is stronger for banks headquartered in periphery countries.

Our paper adds to various strands of the academic literature. First, 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) 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 credit risk plays a larger role than (precautionary) liquidity hoarding.[2] 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), which are largely associated with bank-to-bank information asymmetry problems in the literature. We show that cross-border loans have different liquidity supply restrictions in crisis times. In particular, our results on cross-border loans show substantial heterogeneity depending on the country where the borrower bank is headquartered. Moreover, 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 the supply of interbank liquidity, in particular identifying the effects at the lender-borrower level and

[2]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).

controlling for lenders' and borrowers' fundamentals with a large set of fixed effects.

Second, we contribute to the literature on the identification of credit supply and rationing in credit markets. Given the nature of the interbank data, as compare to the other credit markets, we can observe during a 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 somewhat higher rates – despite that she also borrows on the same morning from another lender at higher prices – where these different prices can rise up to 100 basis points in the crisis. Given that our results show that interbank access and volumes are substantially more affected than interbank prices, and that for the borrower banks with access there are even substantial different prices for identical loans in the same morning for the same borrower, our results suggest some rationing (Berger and Udell, 1992, for a crucial contribution).[3] Moreover, on the supply of credit, Khwaja and Mian (2008) and Paravisini (2008) show that – in order to identify the credit supply – loan-level (lender-borrower level) data is required. These papers compare different business loans from the same borrower in the same quarter or year 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 differ) 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 day or even morning, we can get a better measure of credit supply restrictions.

Third, we contribute to the literature on monetary policy and interbank markets. A crucial channel of the transmission of monetary policy to the economy is through the interbank market, but due to the financial crisis, 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

[3]For the theory of credit rationing, 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). Our findings suggest that theory on credit rationing should give more importance to settings in which competition is not perfect, such as over-the-counter markets as opposed to centralized markets, and different lenders can provide different rates to the same borrower at the same time.

(see also Kiyotaki and Moore, 2012, Gertler and Karadi, 2011, 2013). At the micro level, Diamond and Rajan (2006) and Bolton and Freixas (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 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 an important impact on interbank liquidity and the effects are stronger for borrowing banks (in weaker periphery) countries (though not for riskier borrowing banks in these countries).

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 euro area sovereign debt crisis in 2010 is generally perceived as being caused by increased worries about imminent 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, de Andoain, Hoffmann, and Manganelli, 2014). 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 LTRO. Our results show that – even for the highly integrated interbank market – financial integration achieved in the euro area prior to 2008 was not crisis-resistant. 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. Our results, however, show that unconventional monetary policy measures mitigate this geographical segmentation. This indicates that a reintegration of the euro area money market depends on banks' incentives to reestablish cross-border interbank lending. While this happens, monetary policy liquidity measures are of utmost importance to reduce interbank liquidity frictions.

The remainder of this paper is structured as follows. Section 2 describes our dataset. Section 3 discusses our identification strategy and econometric models. In Section 4 and 5, we present the results of the empirical analysis, first for the liquidity supply with all overnight and 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 pairs of credit institutions in the euro area. 91% of the aggregate Target2 turnover refers primarily to interbank payments as it settles payments 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.[4]

There are three main advantages of using Target2 interbank transaction data compared with the U.S. Fedwire or any other major payment system. First, in Target2 the payment legs of interbank money market transactions are classified as interbank credit payments. This is crucial for the identification of unsecured interbank loans. Given that we only focus on these interbank transactions, we match the two legs (i.e. the initial payment and the repayment) of an interbank loan and obtain further details on the trade (prices and maturities) by employing a refined version of the Furfine (1999) algorithm as developed by Arciero et al. (2013). One major advantage of this algorithm is that it is constructed so as to also identify term interbank loans of up to one year.[5]

[4]Money market transactions 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, see Arciero, Heijmans, Heuver, Massarenti, Picillo, and Vacirca (2013).

[5]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 to de Frutos, Garcia, Heider, and Papsdorf (2014)).

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 information is crucial for the identification of the lender's and borrower's country of origin, which is needed to identify cross-border interbank loans and banks headquartered in crisis countries.[6] 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 (identifying 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, the 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 are no such interbank transaction data available (Armantier and Copeland, 2012).[7]

Our dataset contains the interbank loans between two credit institutions settled via Target2 in the period from June 2008 (when Target2 starts and has consistent data for all countries) to mid-2012 (before the interest rate paid on reserves was set to zero and the ECB started the OMT operations following President Draghi's speech at the Global Investment Conference in London in July 2012).[8] The interbank lending 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,

Our main results remain qualitatively unaffected by these changes to the algorithm-based identification technique.

[6]For further information see the Appendix B.

[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]See `http://www.ecb.europa.eu/press/key/date/2012/html/sp120726.en.html`.

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 Santander (Spain) will be reflected in our dataset and considered as cross-border trade while a loan between, say, Deutsche Bank (Germany) and Deutsche Bank (Spain) will not be included.[9] Also, to account for the different branches and subsidiaries, we have consolidated banks on the first eight digits of their 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 interbank lending database for those banks for which we have balance sheet information from 2007 to 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.[10] 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 her 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) spread 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 August 18, 2008 to November 9, 2008 (60 days, with 4 weeks before and 8 weeks after Lehman Brothers failure) defines henceforth the Lehman period and the sample from January 1, 2010 to December 31, 2011 (104 weeks) circumscribes the sovereign (debt crisis) period hereafter.[11] Given the short time period for Lehman, we estimate all our models with data at daily frequency. For the Lehman period, we also use a reference period before the sample used in the regressions to calculate some variables, in particular June and July 2008. For the longer sovereign crisis period, estimation at daily frequency is for most specifications computationally not feasible; we therefore use weekly

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

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

[11] 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.

data and resort to daily data only for the regressions, where we study the price dispersion during the day (or morning). When we analyze the LTRO in some regressions, we use data until April 2012 (and in robustness until June 2012). In case of multiple loans for the same bank pair during one day (or week), we aggregate volumes and compute the quantity-weighted interest rate. That is, all the different overnight loans between a lender and a borrower in a day (or week) are aggregated and thus in our paper we use the expression 'at the loan-time level' to denote the lender-borrower-day (or week) level.

2.2 Summary Statistics

During the Lehman period, for the overnight interbank money market, we observe 265 and 203 distinct lenders and borrowers and a total of 3,032 distinct active bank pairs. This corresponds to a total of 13,661 overnight loans and a daily average of 228 loans. On average, the daily volume borrowed per loan amounts to EUR 87.04 million. The interest rate paid varies 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 19.94% coming from foreign lenders. Our average lending (borrowing) bank's total assets amount to EUR 127.05 (164.55) billion with an equity ratio of 8.0% (6.9%).[12]

For the period after 2010 (sovereign crisis sample), our dataset reflects interbank transactions between 326 lending banks and 286 distinct borrowing. This amounts to a total of 5,365 different bank pairs and 60,695 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 lending (borrowing) bank's total assets are EUR 106.99 (122.50) billion with an equity ratio of 8.1% (7.4%).

For newly granted 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 of these banks borrow EUR 89.16 million

[12]We present summary statistics of our bank balance sheet data in an online appendix, which will be available on `http://www.bundesbank.de/Redaktion/EN/Standardartikel/Bundesbank/Research_Centre/Researchers/abbassi_puriya.html`

per day in this segment and pay prices that vary daily with a standard deviation of about 25 basis points around the daily mean rate; see 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 in this segment. An average of 12 borrowing banks is borrowing on a weekly basis at rates of about 27 basis points 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 borrowing in the overnight segment only.

3 Empirical Strategy

This section describes how we identify the supply of wholesale funding liquidity to study the effects of the crisis periods and monetary policy measures, and the heterogeneous effects depending on cross-border lending and borrower bank risk. We therefore elaborate on the empirical strategy along with the definitions of variables and the econometric models. For empirical identification, we crucially draw on the aforementioned data on (lender-bank-to-borrower-bank) loan-time level data from mid-2008 to mid-2012.

In our empirical strategy we rely on two sets of analyses. The first is based on all lending conditions in the interbank market, while the second is centered on loan prices and is new to the literature on credit restrictions. More precisely, in the first part, we analyze access to interbank overnight funding (i.e. the extensive margin), and, conditional on obtaining 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 not only at the loan level with a strong set of fixed effects to identify the supply of funds, but also at the (borrower) bank level to analyze any potential substitution effects to the reduced supply from some (lender) banks or from some lending relations (e.g. a cut in the cross-border segment could be compensated with higher domestic loans). Due to the high lending activity in the overnight segment, there are – in contrast to the term segment – several loans to the same borrower from different lenders at the same time, as well as several loans from the same lender to different borrowers at the same time.

Therefore, we have to confine our analysis at the loan level with a substantial set of fixed effects to the overnight segment, while we do the analysis at the borrower-bank level on both overnight and term lending.

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 shed light on liquidity restrictions as contracts are identical but prices can be very different. We analyze first the variation in interbank loan prices for the same borrower during the same morning (or day) and second who offers a given borrower in the same morning (or day) lower prices (domestic vs. cross-border lending). Furthermore, we study 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 crises 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 Brothers failure was more exogenous to the euro area, while there is a substantial heterogeneity in the euro area sovereign crisis that we also 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 on October 15, 2008 (announced on October 8) and the first three-year long term refinancing operation (LTRO) in December 2011 (announced on December 8, 2011 and effective on December 22). In the context of the first measure, the Eurosystem allowed banks to borrow as much as they wanted (against eligible collateral) at a pre-announced fixed rate. Before the introduction of these measures, the Eurosystem conducted a multi-unit price-discriminatory auction, where the Eurosystem decided the volume of liquidity to provide within a 'pay-as-you-bid' auction setup (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, see Cassola, Hortaçsu, and Kastl, 2013). The three-year LTRO also follows the fixed-rate full allotment approach but grants central bank loans for the period of three years

(rather than weeks or months) against a larger set of eligible collateral. See Bundesbank (2014) for the euro area monetary policy operations throughout the crisis.

3.1 Supply of Interbank Liquidity and Loan Terms

To identify the supply of interbank liquidity, we need to control for borrower-specific fundamentals that proxy for both higher counterparty risk (see Afonso, Kovner, and Schoar, 2011, and the references therein to interbank counterparty credit risk). As a consequence, we use lender-bank-to-borrower-bank loan-time 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), where the variation is at the bank-to-bank level, we control for lenders' lending costs (other than interbank lending) and liquidity hoarding (Allen, Carletti, and Gale, 2009, Diamond and Rajan, 2009). Therefore, we also add lender*time fixed effects (Jiménez, Ongena, Peydró, and Saurina, 2012 and 2014). Furthermore, as we exploit the Lehman and sovereign crisis shocks to estimate time-varying effects of cross-border, we can add lender-borrower fixed effects to account for time-invariant effects of cross-border (and other persistent lender-borrower characteristics such as similar business models, being part of a formal liquidity network, and distance).[13] All these fixed effects in loan-time level data allows us to identify how the supply of liquidity changes during the course of the crisis (also as compared to normal times), but we also report all main specifications without any fixed effect.

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 just only one counterparty in our estimation sample. Therefore, the remaining loans in the restricted sample are from borrowers and lenders who each receive/provide 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 prior to the estimation period that include the Lehman and sovereign debt crisis, as we explain below. 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 lending data,

[13] Apart from geographical distance, Gabrieli and Georg (2014) argue that banks' position in the interbank lending network matters for liquidity access and conditions.

our econometric specification then takes the following form:

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

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 100 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 ($\text{Access}_{i,j,t} = 100$), then we also observe the loan conditions.

For the intensive margin, $\text{Loan}_{i,j,t}$ reflects the loan conditions, i.e. price and volume. If no trade occurs, then we do not have any information on this margin. We measure the volume ($\text{Volume}_{i,j,t}$) as the logarithm of the respective loan amount in EUR million from lender i to borrower j, and the price ($\text{Spread}_{i,j,t}$) as the spread between the rate paid for the granted loan and the daily mean interest rate (in basis points). $\text{Crisis}_{j,t}$ 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 (in %), and to the five-year sovereign CDS spread of the country where the borrowing bank j is headquartered for the sovereign crisis sample (in log basis points).[14]

$\text{Cross-border}_{i,j}$ is a dummy variable that equals the value one whenever the borrower and lender banks are headquartered in different countries, and zero otherwise.[15] For the sovereign

[14] We use a five-day moving average of the daily CDS spreads. Note that we use these variables to proxy for different moments of the crises. However, all of our empirical analysis could be employed without these observable crisis measures and instead estimate for each day in a non-parametric way all the different lending margins and plot our coefficients over time in charts. The results would remain qualitatively unchanged. Therefore, we could also use different proxies to account for both the financial and sovereign debt crisis. For instance, for the Lehman period, we employ (i) the three-month Euribor-Eurepo spread as well as shorter and longer-dated Euribor-OIS spreads. The Eurepo is a 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 (ii) a binary variable instead of the three-month Euribor-OIS spread that takes the value one as of September 15, 2008 and zero beforehand. For the sovereign period, we replace (i) the borrower's country CDS spread by the mean of the periphery country CDS spread. Also, we compute (ii) each borrower's country CDS as a difference to the German CDS. Moreover, we (iii) use dummy variables for the different stages of the sovereign debt crisis corresponding to the sub-periods marked by the following dates: April 23, 2010 (when Greece first took recourse to the Eurosystem's financial stability facility), July 1, 2011 (Italy and Spain encountered growing funding problems) and the announcement of the first three-year LTRO in December 2011. None of these robustness checks changes our results qualitatively.

[15] For cross-border lending, we further study heterogeneous effects depending on the lender's and borrower's country of 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.

crisis period, we study the heterogeneity of cross-border interbank overnight loans depending on the country where the bank is headquartered. More precisely, we study the heterogeneity of core (Austria, Belgium, Germany, Finland, France, and the Netherlands), large periphery (Spain and Italy), and Troika-rescued periphery (Greece, Portugal, and Ireland) country banks. We define for each group of countries a dummy variable that equals the value one if the borrowing bank is headquartered in the respective country group, and zero otherwise.

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. As another control variable, we include measures to proxy previous strong relationship (see Furfine, 2001, and Cocco, Gomes, and Martin, 2009, Bräuning and Fecht, 2012, and Afonso, Kovner, Schoar, 2013). We define it as a binary variable that takes the value one for the lender i from whom the borrower j obtained most of its overnight funding (in terms of volume) during a respective pre-crisis reference period. For the Lehman period estimations, we construct the relationship variable on the basis of the period from June 1, 2008 to August 9, 2008.[16] Given that our data starts in June 2008, we use a longer reference period for the sovereign sample ranging from September 7, 2009 to end-2009 and the results are very similar if we take almost 18 months of data (from June 2008 to December 2009). Our measure of relationship captures the main lender for each borrower in each reference period, but this lender may not necessarily be the main lender over a longer time horizon.[17] Further, we include further interactions between our crisis measure and the cross-border dummy, the relationship lending variable, and the borrower's asset size and equity ratio, respectively.

We estimate Equation (1) by ordinary least squares (OLS).[18] We first estimate our models without controlling for any fixed effect to analyze all the effects related to liquidity, and then saturate the regressions with fixed effects progressively, and end our tables with the representation in Equation (1) that refers to the specification with the strongest set of fixed effects (and thus with

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

[17]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.

[18]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 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).

our strongest identification). We compute heteroskedasticity-robust standard errors clustered at the bank-to-bank level.[19] In the specification with the strongest set of controls, the lender-bank-to-borrower-bank 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 across the following dimensions: (i) the comparison of the loans to the same borrower at the same time from different lenders, (ii) the comparison of loans from the same lender at the same time to different borrowers, and (iii) 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 (in terms of turnover) interbank term 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. the supply of cross-border loans, it is important to also study the interbank liquidity changes at the (borrower) bank level. At the bank level, our access variable ($\text{Access}_{j,t}$) equals 100 if bank j borrows in the overnight market at time t. The borrowing volume ($\text{Volume}_{j,t}$) is calculated as the logarithm of the total borrowing amount in period t in EUR million. We measure the price of total interbank borrowing ($\text{Spread}_{j,t}$) with the volume-weighted average spread between the rates paid and the daily mean price (in basis points). Similar to our bank-to-bank level analysis, we mainly focus on the overnight segment of the 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) on which a bank borrows in the overnight interbank market, a binary variable that equals the value 100 if the bank also borrows in the term segment (maturity larger than one week) during the same day (or week), and zero otherwise (i.e. the bank only borrows overnight). This defines our extensive margin of term credit ($\text{Term access}_{j,t}$). Conditional on borrowing in the term segment, we also observe the intensive margin of credit, i.e. the volume and the price of credit. We compute the volume ($\text{Term volume}_{j,t}$) as the logarithm of the total term borrowing amount in EUR million, and compute the price of the interbank term borrowing at time t ($\text{Term spread}_{j,t}$) as the average

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

spread to the daily mean rate of all loans for four different maturity bucket (in basis points).[20]

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

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

where $\text{Loan}_{j,t}$ follows the same rationale of Equation (1) and reflects several margins (access, spread, and volumes) of newly granted credit to borrower j at time period t. We estimate these equations for both the overnight and term interbank market. Unlike in our bank-to-bank-level specifications, Cross-border borrowing ratio_j measures the predetermined (reference period based) bank-level cross-border interbank borrowing relative to bank asset size. We use the same pre-crisis reference period as in the loan level specifications. The vector $x_{j,t}$ contains bank balance sheet characteristics and a measure that proxy relationship lending. To that aim, we construct the variable Borrowing concentration ratio_j that corresponds to the total interbank overnight loan amount that borrower j obtains from its most important (in terms of loan amount) lender over the reference period as a share of its total interbank borrowing during the same reference period. We estimate Equation (2) using OLS and saturate the regressions progressively with fixed effects.

3.2 Price Dispersion and Monetary Policy

In the second part of our empirical analysis we focus on the dispersion of prices of identical interbank loans.[21] In the previous subsection we have analyzed access to interbank loans, and suppose now we observe at least two overnight unsecured interbank loans to the same borrower

[20] We construct the following interbank term buckets . The first one contains all loans with a maturity larger than one week and less than 31 days. The second bucket includes all loans with a maturity larger than 31 days but less than or equal than 60 days. The third bucket contains loans with a 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 1,340 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.

[21] Recall that, we use the expression 'identical contract', 'identical loan' and 'identical transaction' interchangeably, where 'identical' refers to an overnight loan to the same borrower at the same point in time.

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 suppose further that 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. Will the prices be 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. she is hoarding liquidity, or because some lenders have different lending (opportunity) costs? 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 (during the crisis and depending on monetary policy), across borrower banks (riskier versus less riskier) and lender-borrower pairs (depending on cross-border lending)?

To answer the above questions, we analyze the unsecured overnight loans to the same borrower in the same morning (or day) in two ways. First, we use prices of different loans to the same borrower in the same time period (morning or day) to compute a statistic that measures the degree of price dispersion at the borrower-morning (or day) 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, once we show that there are substantial differences in prices for the same borrower in the same morning, we analyze at the loan level whether the prices for the same borrower in the same morning are different for cross-border 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, where time is either morning or day. 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) or day.[22]

Moreover, we keep only loans from lenders who grant loans to at least two different (borrower) banks during the early morning (or day). As the lender gives more funds to at least one other

[22]For the analysis of price dispersion, we need at least two loans during the morning (or day). In the previous section, we analyze the extensive margin of obtaining at least one interbank loan. In this section, we need at least two loans. We could analyze the granting of loans and in the second stage the dispersion of price in a two stage model, estimated with Kyriazidou (1997). Results are qualitatively similar.

bank, this restriction ensures that the lender is not liquidity constrained. In addition, as some lenders may have different lending (opportunity) costs (Brunnermeier, Eisenbach and Sannikov, 2012), in some regressions we further clean the different lending rates by lender*time fixed effects in the following way: we regress the loan rate at the lender-borrower-time level 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. In a similar way, we can clean the interest rates by different loan amounts given by each lender. Therefore, in the regression of price dispersion at the borrower-morning level, when we say that we apply lender*time and loan volumes controls, it means that we apply those controls in the loan level data on interest rates to construct a measure of price dispersion (based on the residuals) for the same borrower during the same morning (or day) but cleaned by lenders' cross-sectional and time varying heterogeneity.

Finally, on the basis of the residuals we obtain from the interbank loan rates and construct our measure based on the volume-weighted difference in prices (compared to the minimum one) in the different interbank overnight borrowing from different lenders to the same borrower during the same morning.[23] 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 (or day).

To analyze how the crisis shocks and the two main non-standard monetary policy measures introduced by the Eurosystem affect our measure on price dispersion, we estimate the following model using OLS:

$$\text{Price dispersion}_{j,t} = \beta_1 \text{Crisis}_{j,t} + \beta_2 \text{Policy}_t + \beta_3' x_{j,t} + \text{fixed effects} + \epsilon_{j,t}, \tag{3}$$

where Crisis refers as in Equation (2) to the three-month Euribor-OIS (Crisis$_t$) for the Lehman

[23] Alternatively, in robustness, we also compute (i) the 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. 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 from the minimum rate for the total amount borrowed.

crisis period and the borrower's country CDS spread ($\text{Crisis}_{j,t}$) for the sovereign debt crisis sample, respectively. Policy_t captures the crucial monetary policy measure in each one of the estimation samples. For the Lehman period, it is defined as a binary variable that equals the value one for all days as of the Eurosystem's announcement of the fixed-rate full allotment (Full Allotment_t) policy, and zero before. For the sovereign debt crisis sample, the dummy (LTRO_t) takes the value one for any day as of the announcement of the three-year longer-term refinancing operation, and zero otherwise.[24] We analyze this regression without any control or fixed effect, and subsequently include several fixed effects and controls to study the variation of our price dispersion in order to understand which factors are affecting this price dispersion, in particular we can control in Equation (3) for borrower fixed effects and time-varying borrower controls (as in Equation 2). Moreover, in the construction of our price dispersion measure we can clean the interbank loan rates by lender*time and lender-borrower-time loan volume, as discussed in detail above.

To further analyze the bank-level heterogeneity and to answer whether worse borrowers have a higher price dispersion, we analyze whether borrower risk matters throughout the different subsamples of the crisis period. Given that the bank variables from Bankscope are only based on accounting balance sheets and cannot capture in real time (or daily) the 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 also control for the total amount borrowed and the number of lenders during the same morning. To study the borrower risk heterogeneity we analyze the q^{th} conditional percentile of the price dispersion in the following model:

$$\text{Price dispersion}^q_{j,t} = \beta^q_1 x_{j,t} + \beta^q_2 \text{Borrower risk}_{j,t} + \epsilon^q_{j,t}, \tag{4}$$

where $\text{Borrower risk}_{j,t}$ is the quantity-weighted average interest rate spread (to the daily, volume-weighted, mean price of all overnight interbank loans in basis points that prevailed on the previous day). The time-varying bank-specific vector of control variables $x_{j,t}$ includes the total amount borrowed (defined as the logarithm of the total loan amount borrowed during the same morning, for the number of lenders for the same borrower during the same morning and both the borrower's

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

lagged asset size and equity ratio. We estimate these quantile regressions for the 50th, 75th, and 90th percentile ($q = 50, 75, 90$), as we are particularly interested in the upper tail of the distribution.

Finally, we study the heterogeneity in prices of interbank cross-border loans. By controlling for borrower*time fixed effects, we analyze whether interbank prices differ across different lenders to the same borrower in the same morning (or day). Moreover, as some lenders may be liquidity constrained or have different lending (opportunity) costs, we also control for lender*time fixed effects. Additionally, we also control in some specifications for the interbank overnight 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:

$$\begin{aligned} \text{Spread}_{i,j,t} &= \beta_1 \text{Cross-border}_{i,j} + \beta_2 \text{Volume}_{i,j,t} \\ &+ \beta_3 \text{Cross-border}_{i,j} \times x_{j,t} + \text{fixed effects} + \epsilon_{i,j,t}, \end{aligned} \tag{5}$$

where the right-hand-side variables are computed in the same way as in Equation (1). As opposed to the regression discussed in Equation (1), we do not interact our key variables with crisis proxies as this is already done in the previous equations and in this part of the analysis we are interested in 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 crisis samples. Given the main developments of the crises 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, i.e. the reserve maintenance period before Lehman Brothers filed for bankruptcy, (ii) first two weeks post-Lehman, when term interbank lending drops while overnight lending increases slightly (as shown below), (iii) third to fourth week post-Lehman, i.e. the last two weeks before the actual implementation of the fixed rate full allotment policy and also when aggregate overnight lending starts to decrease (as discussed below), and (iv) fifth to twelfth week post-Lehman, when the fixed-rate full allotment becomes effective. For the sovereign crisis samples, the sub-periods are: (i) January 2010 through April 2010, i.e. before Greece first sought

financial support, (ii) May 2010 through June 2011, where the sovereign debt crisis intensified in 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 throughout the two crisis samples, both at the lender-bank-to-borrower-bank (loan) level and at the borrower bank level. We begin the discussion of our results with those for the Lehman period, and then move on to 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.[25] We first analyze the time variation of access and loan conditions during the crisis. An increase of the Euribor-OIS spread is associated with a significant drop in bank-to-bank funding access, as Column (1) shows, amounting to a maximum of 2.83 percentage points ($1.98 \times (2.07 - 0.64)$) at the worst moment of the crisis, i.e. when the the Euribor-OIS spread peaked at 2.07.[26] Compared to the average loan probability of 5.9% before the Lehman Brothers failure, this change corresponds to a relative reduction of access by about 47% in the worst moment of the Lehman crisis. Conditional on having access to interbank liquidity, we find no statistically significant effect of the crisis on interbank prices and volumes of newly granted loans. Therefore, the strongest effects are on the extensive rather than the intensive margin of interbank liquidity.[27]

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

[26] The Euribor-OIS spread increased dramatically by 1.43 percentage points after the Lehman Brothers failure from an pre-Lehman average value of 0.64% to a maximum value of 2.069% on 10 October 2008. As we explained in the Empirical Strategy, we could provide the results for the supply of interbank liquidity for each day in the sample period. By using an observable time-varying measure of crisis, such as Euribor-OIS or later sovereign CDS, we analyze whether in the worst moments of the crisis there are stronger supply restrictions on interbank liquidity.

[27] 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. Once we add all the fixed effects, our results can only be analyzed in the restricted sample. See the previous section.

We also analyze the compositional effects of the supply of interbank liquidity with respect to cross-border transactions. We find that cross-border loans are about 2.35 percentage points less likely than domestic loans (i.e., loans 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 3.55 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 1.54 percentage points at the peak of the Euribor-OIS ($-1.08 \times (2.07 - 0.64)$). In Column (4), we present the estimation results for our full model including both lender*time and borrower*time fixed effects as well as lender-borrower pair fixed effects. The level effect of cross-border liquidity is absorbed in the lender-borrower-fixed effects, and despite the substantial increase in the unobservables that we control for with these three sets of fixed effects, the main coefficient of the interaction term of cross-border with the Euribor-OIS remains very similar.

For the intensive margin, Columns (7), (8), (11) and (12) imply that the supply of interbank liquidity also 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 12.87% ($0.09 \times (2.07 - 0.64)$, see Column 12) and an increase in prices by roughly 9.02 basis points ($6.31 \times (2.07 - 0.64)$) at the peak of the crisis. Note that it is important to control for lender and borrower heterogeneity, as the comparison between Column (9) with either (10) or (11) suggests. For instance, 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, with substantially stronger effects for access and volume rather than prices.

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 worst moment of the Lehman crisis (i.e. at the peak of the Euribor-OIS spread), borrowing in the overnight segment becomes 14.70 percentage points less likely on average ($10.28 \times (2.07 - 0.64)$, Column 2). This drop corresponds to a reduction in access of up to 35% relative to the average borrowing probability of 42% before the Lehman failure. At the same time, we estimate a maximum drop in the total overnight borrowing amount of 22.88% ($0.16 \times (2.07 - 0.64)$, see Column 7). Moreover,

Column (9) and (10) indicate that the percentage share of cross-border loans in banks' overnight interbank borrowing volume decline on average by almost 5.5 percentage points at the peak of the Lehman crisis, corresponding to a relative change of 25% relative to the pre-Lehman mean value of 21.7%.

Our results also suggest heterogeneity in wholesale funding. At the worst of the crisis, banks with a larger share of ex-ante cross-border funding relative to their asset size (two standard deviations above mean) pay up to 14.95 basis points more for overnight interbank borrowing than those with relatively weak ex-ante cross-border linkages (two standard deviations below mean) during our ex-ante pre-crisis reference period ($4 \times 0.29 \times 9.01 \times (2.07 - 0.64)$, see Column 5).[28]

The overall decrease in overnight access of credit extends to the term segment (maturity beyond one week), where the reduction is quantitatively even stronger and aggregate lending volumes drop faster immediately after the Lehman 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 the Lehman failure, where overnight goes up when term lending decreases significantly. In the period thereafter, when term volumes stop declining and remain at 80% below the pre-Lehman mean, overnight volumes also start to decrease.[29] 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. We estimate a drop in the likelihood of a term interbank loan by up to 19.08 percentage points ($-13.34 \times (2.07 - 0.64)$, see Column 2) at the peak of the Euribor-OIS spread. Relative to the pre-Lehman mean value of term access (76.6%), this corresponds to a reduction of 24.80%.[30] Moreover, the decrease in the daily term loan amount reaches a level of up to 61% at the worst moment of the Lehman 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 during the

[28] The cross-border bank level variable is very different from our loan level cross-border variable. See Appendix A for the exact definitions and the previous section.

[29] For the U.S. federal funds market, Afonso et al. (2011) find that the overnight U.S. money market was stressed, but not frozen, immediately after the Lehman Brothers failure.

[30] As discussed in the Empirical Strategy, our binary term access variable is defined only for those bank-day observations, where the respective bank has access to the overnight segment.

crisis than during tranquil times.

In sum, our robust results suggest that the Lehman crisis implies lower access (with a maximum reduction of 25%) and lower volume (61%) in term maturity interbank liquidity. For the overnight segment, there is lower access by about 35% (47% reduction of access at loan level) and lower granted volumes by 23%. Moreover, the interbank liquidity supply restrictions during the crisis particularly worsen for cross-border lending, again with substantial stronger effects for access and volumes rather than spreads.

4.2 Evidence for the 2010-2012 Sovereign Debt Crisis

For the sovereign period, the results suggest that a higher CDS spread of the country where the bank is headquartered is associated with less funding access and higher prices for overnight interbank loans, as Panel A of Table 4 shows. The estimated coefficient in Column (2) implies a decrease in funding access by about 5.47 percentage points ($-3.40 \times (5.98 - 4.37)$) at the worst moment of the crisis (when the average log CDS spread of those countries represented in the sample peaks at a value of 5.98 at the end of 2011 compared to the pre-crisis minimum value of 4.37 at the beginning of 2010, a change of 1.61). This corresponds to a relative reduction in access of about 58.99 %. At the same time, prices of granted loans increase by about 28.81 basis points ($17.90 \times (5.98 - 4.37)$), as implied by our estimates in Column (7).

This heterogeneity in liquidity conditions stems not only from the time variation of the overall euro area crisis but also from the heterogeneity across euro area member countries.[31] Figure 2 illustrates the country-group heterogeneity graphically. As Panel A of Table 4 shows, supply restrictions to overnight interbank access in crisis times are largely pronounced for banks headquartered in Troika-rescued periphery countries, with an additional reduction of access by 2.96 percentage points on top of core country banks (reduction of 1.37 percentage points) as a response to a 100% increase in CDS spreads (Column 4). This change corresponds to a relative reduction of access by about 23.8% for core country banks and by about 75.1% for banks from Troika-rescued periphery countries during the worst moment of the sovereign crisis (i.e. when the average log CDS peaked at 5.98 at the end of 2011). The price of interbank liquidity increases

[31] The cross-sectional variation (measured by the maximum log CDS minus the minimum log CDS on each day) increases from a minimum value of 2.11 at the beginning of 2010 to the maximum of 5.12 at the end of 2011.

for all periphery country banks, but not for core country banks. The increase is of the same magnitude (19.69 to 23.5 basis points relative to core country banks) for both Troika-rescued and large periphery country banks, as Column (9) shows.

In cross-border lending conditions, we also 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 2.84 percentage points per 100% increase in CDS spreads, see Column (5). Compared to the average cross-border loan probability of 4.6% from January to March 2010, this corresponds to a relative change in access to cross-border funding by about 99.4% during the worst moment of the crisis ($-2.84 \times (5.98 - 4.37)$), see also Figure 2 (b) for an illustration of this dramatic reduction. While for volumes, the compositional effects across core and periphery country banks are similar, for prices, we find the largest effects for cross-border loans for Troika-rescued periphery country banks (marginal effect is 31.51 basis points higher) followed by large periphery country banks (12.23 basis points higher as compared to core banks).

Our bank-level results, as Panel B of Table 4 suggest, are in line with our bank-to-bank analysis, as they all point towards 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 countries, except for spreads where large periphery banks pay more than 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 reductions – both overall and cross-border – are binding. The loan-level analysis is crucial in order to identify the supply of liquidity, as we can control for time-varying unobserved and observed heterogeneity in borrower fundamentals, and even lenders' heterogeneity for the compositional supply effects, such as risk or Eurosystem's liquidity provision.

Our results suggest that the crisis is also associated with lower access and volume in the longer-term maturity interbank liquidity (which we graphically illustrate in Panel B of Figure 1), whereas there is no effect on spreads. Economically, an increase in the CDS spread by 100% reduces the likelihood of term interbank borrowing by 11.15 percentage points, see Column (4). This amounts to a reduction in term access of about 17.95 (-11.15×1.61) percentage points

for borrower banks in worst countries (with CDS spread at 90th percentile). We also find that banks from the large periphery differentially pay higher rates in the term segment when their country CDS spread increases.

In total, our results for the sovereign sample yield results similar to those for the Lehman sample, i.e. lower access and volumes but higher spreads in both the overnight and term segments, and again substantial stronger effects on access and volume than spreads. However, we find important heterogeneity depending on the countries where the borrowing bank is headquartered. For instance, supply restrictions to cross-border interbank access in crisis times are only binding for Troika-rescued periphery country banks, with a maximum relative reduction of 99.4% compared to the pre-crisis period and an increase of prices for newly granted cross-border loans by up to 31.51 basis points (relative to spreads paid by core country banks). For large periphery country banks, we do not find any significant effect on access but 23.5 basis points higher spreads relative to core country banks.

5 Results on Price Dispersion and Monetary Policy

In this section, we present the results on our price dispersion measure explained in the section on empirical strategy. In addition, we analyze the effects of the most substantial monetary policy measures until mid-2012, i.e. the announcement of the fixed-rate full allotment policy and the three-year LTRO. We begin to present our results for the Lehman crisis period and then those for the sovereign crisis period.

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

We analyze the price dispersion measure on identical loan contracts (overnight uncollateralized loans to the same borrower in the same day or morning) from three different angles: its heterogeneity across time (different moments of the crises and monetary policy), the heterogeneity across borrowing banks (e.g. riskier vs. less risky), and the heterogeneity across bank pairs (cross-border as compared to domestic in the pricing for identical contracts). Figure 3 Panel A illustrates the first two dimensions of heterogeneity. After the Lehman failure, the mean of the price dispersion measure increases by up to 25 basis points (from 2 basis points before the

crisis). Thus, the average price differences for loans from different lenders during the same day to the same borrower increase by an average of 25 basis points. Moreover, the difference between the 5th percentile and 95th percentile amounts to more than 65 basis points at the peak of the crisis as compared to less than 10 basis points before the crisis. Some banks even face a price dispersion of up to 100 basis points during a day at the worst moment of the crisis, substantially higher than in the pre-crisis period (where the only strong dispersion occurs on the last days of the maintenance period when reserve requirements become binding).

Given our findings on the time variation of our price dispersion measure in Panel A of Figure 3, we focus in the regressions on those observations that exceed the daily 90th percentile, i.e. where the price dispersion for identical loans is particularly high. The results from Panel A of Table 6 can be summarized as follows. First, in all specifications, our crisis indicator (the three-month Euribor-OIS spread) has a positive and statistically significant effect on the price dispersion. We find that a 100 basis points increase in the three-month Euribor-OIS spread is associated with higher price dispersion for the same borrower during the same day of up to 56.07 basis points (after controlling for borrower fixed effects). On the worst day of the Lehman crisis (crisis indicator is 2.07), this corresponds to an average increase of more than 80.18 basis points ($-56.07 \times (2.07 - 0.64)$, see Column 2) for 10% of all banks. Regarding the monetary policy effect, we find that the announcement of the fixed-rate full allotment monetary policy on October 8, 2008 decreases the price dispersion during the same day by 46.79 basis points. Figure 3 Panel B visualizes this monetary policy effect while controlling for borrower fixed effects.

It is important to note that borrower controls (borrower fixed effects, time-varying borrower controls and lender-borrower controls) do not significantly affect the crisis and monetary policy coefficients, whereas the inclusion of lender*time fixed effects (to construct the price dispersion measure) reduces both the crisis effect by about 15 basis points and the fixed-rate full allotment effect by 10 basis points (Column 2 vs. Column 3). When we restrict the sample to only include loans provided until noon, the number of observations (and thus the variation) drops significantly, and the estimated crisis coefficient decreases to 23.11 and the fixed-rate full allotment effect to 9.41 in our strongest specification in Column (8) (with lender*time fixed effects and loan volume controls in the construct the price dispersion measure, and time-varying borrower controls and borrower fixed effects in the price dispersion regression).

We also study heterogeneity across borrowing banks. In Panel B of Table 6, we analyze whether borrower risk explains the borrower heterogeneity depicted in Panel A of Figure 3, using quantile regressions for the 50th, the 75th, and the 90th percentile (see Equation 4). We proxy bank risk by the previous day's average spread paid to the daily mean rate. The results are as follows. Before the Lehman Brothers bankruptcy, there is no significant effect. Post-Lehman, however, riskier borrowers face a significantly larger price variation during the morning across all percentiles. In fact, the effect strengthens further throughout the crisis subsamples for all percentiles and is quantitatively strongest for the 75th and 90th percentile. These results hold even after controlling for lender*time fixed effects and loan volumes to obtain the price dispersion measure and time fixed effects and borrower controls (the total daily borrowing amount, the daily number of lenders, equity ratio and asset size) in the price dispersion regression. Economically, for the 90th percentile in the fourth subsample, the price dispersion for a bank with an average spread of two standard deviations above the mean is 21.72 basis points ($4 \times 20.61/100 \times 26.10$, see Column 12)[32] higher than a bank with an average spread two standard deviations below the mean. In consequence, the variation depending on borrower risk is less strong than over time.

To understand the price heterogeneity at the lender-bank-to-borrower-bank level, we also analyze the effects of cross-border on the pricing of overnight loans for the same borrower in the same morning during four different sub-periods of our Lehman sample that proxy for different moments of the crisis.[33] To that aim, we estimate our Equation 5, i.e. we analyze each spread for each borrower from each lender while including in all regressions for lender*morning and borrower*morning fixed effects, so as to control exhaustively for time-varying unobservable heterogeneity in borrowers (risk) and lenders (lending costs and liquidity hoarding) thereby leaving the lender-bank-to-borrower-bank level variation as the remaining dimension to be explained.

Our findings presented in Panel C of Table 6 reveal that, for the same borrower in the same morning, cross-border loans are more expensive than domestic loans (e.g. 21.84 basis points in the fourth subsample, see Column 7) 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 (not reported here, but available in the online appendix)

[32] We divide by 100 as our variable Borrower risk$_{j,t}$ is expressed in %, the value 20.61 however represents the standard deviation for the spread in basis points.

[33] In the online appendix version of Table 6, we also provide the estimates for differences in access and volumes.

and also when we control exhaustively for lenders charging different average rates in different days.

All in all, in the crisis there are substantially different prices for the same borrower in the same day or even morning from different lenders. This price dispersion cannot just be explained by lender characteristics (e.g. liquidity hoarding or different lending costs) and is stronger for the riskier borrowers during the crisis period. Moreover, cross-border charge higher prices. Before the Lehman bankruptcy, there are no significant effects on all these previous margins. Finally, the monetary policy action through the fixed-rate full allotment policy substantially reduces the overall dispersion effects, notably on the marginal borrowers by up to 46.79 basis points for the same borrower in the same day.

5.2 Sovereign Debt Crisis and the three-year LTRO

We now present the results for the sovereign crisis period. Panel A of Figure 3 presents the evolution of our price dispersion measure for both the conditional mean and the upper and lower percentiles. The figure illustrates how close our price dispersion measure co-moves with the average (log) CDS spread of periphery countries. Moreover, the upper tail of our price dispersion distribution increases by up to 40 basis points in the worst moments of the sovereign crisis. After the announcement of the three-year LTRO, as Panel B shows, the price dispersion decreases to pre-crisis levels, with substantial stronger effects for periphery (as compared to core) country banks.

We assess the time dimension in more detail in Panel A of Table 7. Again, we run our regressions for observations that exceed the daily 90th percentile value and show that the crisis effect prevails consistently across all specifications. On average, the price dispersion increases by 25 basis points from beginning of 2010 to end of 2011 ($(5.98 - 4.37) \times 15.53$, see Column 2). The cross-sectional differences between banks from countries with the highest country CDS spread and those from countries with the lowest CDS spread increase by roughly 46.7 basis points (from 32.77 basis points at the beginning of 2010 to 79.5 basis points in December 2011). The quantitative effects of our crisis variable can be assigned to banks from the large periphery and the Troika-rescued periphery countries, as Column (3) suggests. Similar to the Lehman sample, the inclusion of lender*time fixed effects explains part of the variation associated with the crisis,

but differently from Lehman, borrower controls (fixed effects, time-varying borrower controls and loan volumes) are also important. Finally, even for loans traded during the same morning we estimate a significant crisis effect of 7.17 basis points for any one-unit increase of our crisis measure (after controlling for borrower fixed effects and time-varying controls, lender*time fixed effects and loan amount controls).

We also study the impact of the three-year LTRO (a dummy variable that equals the value one on all days as of the LTRO announcement). In all specifications, we find a statistically significant and negative effect, thus suggesting that this unconventional monetary policy measure reduces the price dispersion. In the specifications presented in Column (1) to (7), the monetary policy effect amounts to a reduction of the price dispersion by up to 20.84 basis points on average. Column (3) shows that the monetary policy effect has a stronger impact on periphery country banks than on core country banks (6.69 basis points difference).[34] We visualize the monetary policy effect while controlling for (borrower) bank fixed effects in Panel B of Figure 3. It reveals that immediately after the Eurosystem's promise to grant unlimited credit for the period of three years, there is a substantial average decrease in the price dispersion. The reduction accounts for 25 basis points for banks from periphery countries.

In analogy to our Lehman sample analysis, we also study the heterogeneity of our price dispersion measure during the morning at the borrower bank and lender-borrower 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. Furthermore, price dispersion is significantly more pronounced for large periphery and Troika-rescued periphery country banks. Importantly, after the LTRO, the country where the bank is headquartered (periphery vs. core) loses economic significance, while borrower risk (proxied by the bank time-varying spread) gains even more economic significance. Therefore, our overall results suggest that LTRO helped to reduce bank liquidity problems, especially to the periphery country banks, but did not eliminate the market disciplining effect of interbank markets on riskier borrower banks.

We analyze the effects of cross-border 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-

[34] Due to the scarcity of observations involving banks from Troika-rescued periphery countries, we are not able to estimate a separate effect for this country group

periods that proxy for different crisis moments. Recall that our empirical identification applies lender*morning and borrower*morning fixed effects to isolate cross-border loans. Overall, effects are weaker than in the Lehman period, and the negative effects of cross-border loans are stronger for the periphery (as compared to the core country) banks. These effects are not significant before Greek's recourse to the Eurosystem's financial support in May 2010 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 (9.42 basis points) for cross-border loans than core banks, and also for cross-border loans as compared to domestic loans (6.36 basis points, $9.42 - 3.06$ from Column 4), conditioning on the same borrower bank in the same morning.

All in all, in the worst moment 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 simply related to unobserved time-varying lender characteristics and is even higher for the riskier borrowers. Only for periphery country banks, cross-border loans are more expensive. Finally, the three-year LTRO reduces the overall price dispersion (maximum reduction of 20.84 basis points), with stronger effects for periphery country banks. In sum, the effects are qualitatively similar to those we find for the Lehman period but quantitatively weaker for banks from the core countries. Instead, banks from periphery countries are substantially penalized in the 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. Despite the utmost importance of this question for academia and policy, empirical analysis is scarce due to the relative lack of comprehensive micro-datasets, since wholesale transactions are mostly conducted over-the-counter. In this paper, we overcome this hurdle by using a proprietary bank-to-bank euro area interbank dataset extracted from Target2. We also exploit the Lehman and sovereign crises as well as the main Eurosystem non-standard monetary policies on banks for the 2008-2012 period.

The robust results imply that the crisis worsens access, volumes and spreads for overnight and longer-term liquidity, with substantial stronger effects for access and volume as compared to prices. Moreover, after the Lehman failure liquidity supply restrictions particularly worsen for cross-border lending, while some of the effects are quantitatively stronger in the sovereign debt crisis for banks headquartered in periphery countries. Furthermore, the interbank market – unlike other credit markets – allows to exploit the price dispersion from different lenders on identical credit contracts, i.e. overnight uncollateralized loans in the same morning for the same borrower. This price dispersion is highly heterogeneous over time depending on the crisis strength (with substantial increases in crisis times), across borrowing banks depending on borrower risk (with higher increases for riskier banks), and across bank pairs depending on cross-border (cross-border charges higher prices in crisis times). Importantly, this price dispersion for the same borrower in the same morning (or day) decreases when the Eurosystem both provides unlimited access to liquidity at a fixed price and the three-year LTRO.

All in all, both our results on the strong tightening in access and volumes (as compared to spreads), and on the substantial different interbank prices for the same borrower in the same morning (or day), suggest not only a contraction of liquidity conditions in the crisis, but also some rationing. Importantly, non-standard monetary policy substantially softens this tightening. Note that we exploit the price variation in the overnight segment of the interbank market, where we can apply our strong empirical identification. While these results are quantitatively compelling, we believe that our quantitative findings render the lower bound of the crisis induced liquidity problems, as the overnight interbank market should be one of the least risky segments during crisis times. Moreover, the results suggest that information asymmetry problems in interbank markets are important, notably in cross-border lending, and affecting the availability and pricing of wholesale liquidity for banks in crisis periods. These findings have important policy implications. They indicate that a reintegration of the euro area money market depends on banks' incentives to reestablish cross-border interbank lending. While this happens, monetary policy liquidity measures are of utmost importance to reduce interbank liquidity frictions.

References

Acharya, V. V., I. Drechsler, and P. Schnabl (2014). A Pyrrhic Victory? - Bank Bailouts and Sovereign Credit Risk. *Journal of Finance* (forthcoming).

Acharya, V. V. and O. Merrouche (2013). Precautionary Hoarding of Liquidity and Inter-Bank Markets: Evidence from the Sub-prime Crisis. *Review of Finance 17*(1), 107–160.

Afonso, G., A. Kovner, and A. Schoar (2011). Stressed, not Frozen: The Federal Funds Market in the Financial Crisis. *Journal of Finance 66*(4), 1109–1139.

Afonso, G., A. Kovner, and A. Schoar (2013). Trading Partners in the Interbank Lending Market. Staff Reports 620, Federal Reserve Bank of New York.

Allen, F., E. Carletti, and D. Gale (2009). Interbank Market Liquidity and Central Bank Intervention. *Journal of Monetary Economics 56*(5), 639–652.

Allen, F., E. Carletti, and D. Gale (2014). Money, Financial Stability and Efficiency. *Journal of Economic Theory 149*, 100–127.

Allen, F., A. Hryckiewicz, O. Kowalewski, and G. Tümer-Alkan (2010). Transmission of Bank Liquidity Shocks in Loan and Deposit Markets: The Role of Interbank Borrowing and Market Monitoring. Working Papers 10-28, University of Pennsylvania.

Angelini, P., A. Nobili, and C. Picillo (2011). The Interbank Market after August 2007: What Has Changed, and Why? *Journal of Money, Credit and Banking 43*(5), 923–958.

Arciero, L., R. Heijmans, R. Heuver, M. Massarenti, C. Picillo, and F. Vacirca (2013). How to Measure the Unsecured Money Market? The Eurosystem's Implementation and Validation using TARGET2 Data. DNB Working Papers 369.

Armantier, O. and A. Copeland (2012). Assessing the Quality of 'Furfine-based' Algorithms. Staff Reports 575, Federal Reserve Bank of New York.

Berger, A. N. and G. F. Udell (1992). Some Evidence on the Empirical Significance of Credit Rationing. *Journal of Political Economy 100*(5), 1047–77.

Bester, H. (1985). Screening vs. Rationing in Credit Markets with Imperfect Information. *American Economic Review 75*(4), 850–55.

Bolton, P. and X. Freixas (2006). Corporate Finance and the Monetary Transmission Mechanism. *The Review of Financial Studies 19*(3), 829–870.

Bräuning, F. and F. Fecht (2012). Relationship Lending in the Interbank Market and the Price of Liquidity. Discussion Papers 22/2012, Deutsche Bundesbank.

Bruche, M. and J. Suarez (2010). Deposit Insurance and Money Market Freezes. *Journal of Monetary Economics 57*(1), 45.

Brunnermeier, M. K., T. M. Eisenbach, and Y. Sannikov (2012). Macroeconomics with Financial Frictions: A Survey. NBER Working Papers 18102, National Bureau of Economic Research.

Bundesbank, D. (2014). Implications of the Eurosystem's Monetary Operations during the Financial Crisis. Monthly Report April, Deutsche Bundesbank.

Caballero, R. J. and A. Krishnamurthy (2008). Collective Risk Management in a Flight to Quality Episode. *Journal of Finance 63*(5), 2195–2230.

Cassola, N., A. Hortaçsu, and J. Kastl (2013). The 2007 Subprime Market Crisis Through the Lens of European Central Bank Auctions for Short-Term Funds. *Econometrica 81*(4), 1309–1345.

Cocco, J. F., F. J. Gomes, and N. C. Martins (2009). Lending Relationships in the Interbank Market. *Journal of Financial Intermediation 18*, 24–48.

de Andoain, C. G., P. Hoffmann, and S. Manganelli (2014). Fragmentation in the Euro Overnight Unsecured Money Market. *Economics Letters 125*(2), 298–302.

de Frutos, J. C., C. Garcia, F. Heider, and P. Papsdorf (2014). Stressed Interbank Markets: Evidence from the European Financial and Sovereign Debt Crisis. mimeo.

de Meza, D. and D. C. Webb (1987). Too Much Investment: A Problem of Asymmetric Information. *The Quarterly Journal of Economics 102*(2), 281–92.

Diamond, D. W. and R. G. Rajan (2006). Money in a Theory of Banking. *American Economic Review 96*(1), 30–53.

Diamond, D. W. and R. G. Rajan (2009). The Credit Crisis: Conjectures about Causes and Remedies. *American Economic Review 99*(2), 606–10.

Farhi, E. and J. Tirole (2014). Deadly Embrace: Sovereign and Financial Balance Sheets Doom Loops. Working Paper 164191, Harvard University.

Flannery, M. J. (1996). Financial Crises, Payment System Problems, and Discount Window Lending. *Journal of Money, Credit and Banking 28*(4), 804–24.

Freixas, X. and C. Holthausen (2005). Interbank Market Integration under Asymmetric Information. *The Review of Financial Studies 18*(2), pp. 459–490.

Freixas, X. and J. Jorge (2008). The Role of Interbank Markets in Monetary Policy: A Model with Rationing. *Journal of Money, Credit and Banking 40*(6), 1151–1176.

Freixas, X., A. Martin, and D. Skeie (2011). Bank Liquidity, Interbank Markets, and Monetary Policy. *The Review of Financial Studies 24*(8), 2656–2692.

Furfine, C. H. (1999). The Microstructure of the Federal Funds Market. *Financial Markets, Institutions & Instruments 8*, 24–44.

Furfine, C. H. (2001). Banks as Monitors of Other Banks: Evidence from the Overnight Federal Funds Market. *Journal of Business 74*, 33–57.

Furfine, C. H. (2002). The Interbank Market during a Crisis. *European Economic Review 46*(4-5), 809–820.

Gabrieli, S. and C.-P. Georg (2014). A Network View on Interbank Market Freezes. mimeo.

Gertler, M. and P. Karadi (2011). A Model of Unconventional Monetary Policy. *Journal of Monetary Economics 58*(1), 17–34.

Gertler, M. and P. Karadi (2013). QE 1 vs. 2 vs. 3. . . : A Framework for Analyzing Large-Scale Asset Purchases as a Monetary Policy Tool. *International Journal of Central Banking 9*(1), 5–53.

Gertler, M. and N. Kiyotaki (2010). Financial Intermediation and Credit Policy in Business Cycle Analysis. In B. M. Friedman and M. Woodford (Eds.), *Handbook of Monetary Economics*, Volume 3 of *Handbook of Monetary Economics*, Chapter 11, pp. 547–599.

Holmstrom, B. and J. Tirole (1998). Private and Public Supply of Liquidity. *Journal of Political Economy 106*(1), 1–40.

International Monetary Fund (2013). European Union: Publication of Financial Sector Assessment Program Documentation – Technical Note on Financial Integration and Fragmentation in the European Union. Staff Country Reports 13/71.

Iyer, R. and J.-L. Peydró (2011). Interbank Contagion at Work: Evidence from a Natural Experiment. *The Review of Financial Studies 24*(4), 1337–1377.

Jaffee, D. M. and F. Modigliani (1969). A Theory and Test of Credit Rationing. *American Economic Review 59*(5), 850–72.

Jaffee, D. M. and T. Russell (1976). Imperfect Information, Uncertainty, and Credit Rationing. *The Quarterly Journal of Economics 90*(4), 651–66.

Jiménez, G., S. Ongena, J.-L. Peydró, and J. Saurina (2012). Credit Supply and Monetary Policy: Identifying the Bank Balance-Sheet Channel with Loan Applications. *American Economic Review 102*(5), 2301–2326.

Jiménez, G., S. Ongena, J.-L. Peydró, and J. Saurina (2014). Hazardous Times for Monetary Policy: What do Twenty-Three Million Bank Loans Say about the Effects of Monetary Policy on Credit Risk-Taking? *Econometrica 82*(2), 463.

Khwaja, A. I. and A. Mian (2008). Tracing the Impact of Bank Liquidity Shocks: Evidence from an Emerging Market. *American Economic Review 98*(4), 1413–42.

Kiyotaki, N. and J. Moore (2012). Liquidity, Business Cycles, and Monetary Policy. NBER Working Papers 17934, National Bureau of Economic Research.

Kovner, A. and D. Skeie (2013). Evaluating the Quality of Fed Funds Lending Estimates Produced from Fedwire Payments Data. Staff Reports 629, Federal Reserve Bank of New York.

Kuo, D., D. Skeie, and J. Vickery (2010). How Well Did the Libor Measure Bank Wholesale Funding Rates during the Crisis. Working papers, Federral Reserve Bank of New York.

Kyriazidou, E. (1997). Estimation of a Panel Data Sample Selection Model. *Econometrica 65*(6), 1335–1364.

Mankiw, N. G. (1986). The Allocation of Credit and Financial Collapse. *The Quarterly Journal of Economics 101*(3), 455–70.

Paravisini, D. (2008). Local Bank Financial Constraints and Firm Access to External Finance. *Journal of Finance 63*(5), 2161–2193.

Sinn, H.-W. (2013). Austerity, Growth and Inflation. Remarks on the Eurozone's Unresolved Competitiveness Problem. CESifo Working Paper Series 4086, CESifo Group Munich.

Stiglitz, J. E. and A. Weiss (1981). Credit Rationing in Markets with Imperfect Information. *American Economic Review 71*(3), 393–410.

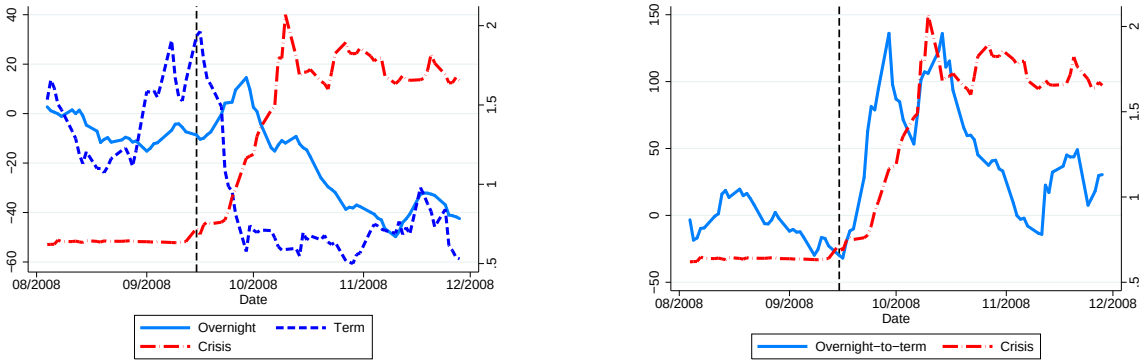
Tölö, E., E. Jokivuolle, and M. Viren (2014). Do Private Signals of a Bank's Creditworthiness Predict the Bank's CDS Price? Evidence from the Eurosystem's Overnight Loan Rates. Research Discussion Papers 9-2014, Bank of Finland.

Uhlig, H. (2013). Sovereign Default Risk and Banks in a Monetary Union. NBER Working Papers 19343, National Bureau of Economic Research.

Wetherilt, A., P. Zimmerman, and K. Soramaki (2010). The Sterling Unsecured Loan Market during 2006-08: Insights from Network Topology. Bank of England Working Papers 398, Bank of England.

Figures

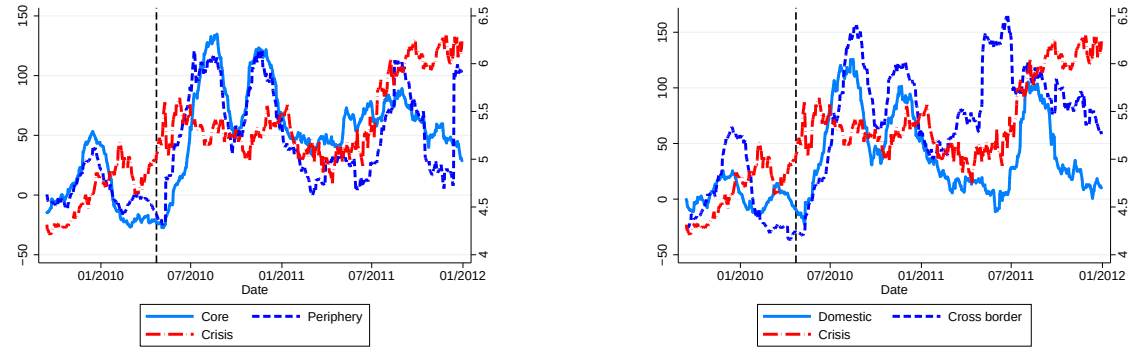
Figure 1 Panel A:
Overnight vs. term interbank lending amount for the Lehman period



(a) Overnight and term **(b) Overnight-to-term ratio**

Notes: Subfigure (a) shows the aggregate daily lending amount during the Lehman sample for both the overnight (solid blue line, left axis) and term (dashed blue line, left axis) segment for the period from August 1, 2008 to December 31, 2008. 'Term' lending relates to transactions with maturity larger than one week. Subfigure (b) depicts the ratio of the aggregate daily lending amount in the overnight segment to the aggregate daily lending amount in the term segment. All three series are expressed as percentage deviations from the mean value of each respective series during the pre-Lehman period from August 1, 2008 to September 12, 2008. 'Crisis' denotes the three-month Euribor-OIS spread (long-dashed red line, in % on the right axis). All series (except 'Crisis') are smoothed with a 10-day moving average. The vertical dashed line corresponds to September 15, 2008, when Lehman Brothers filed for bankruptcy.

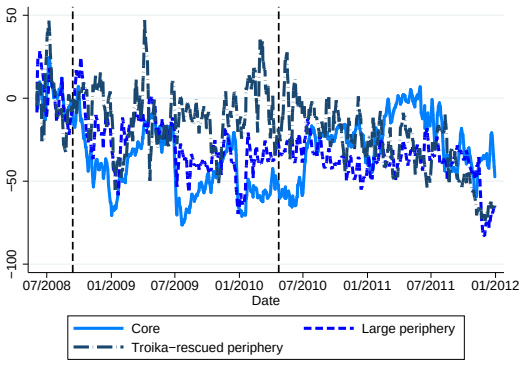
Figure 1 Panel B:
Overnight vs. term interbank lending amount for the sovereign crisis period



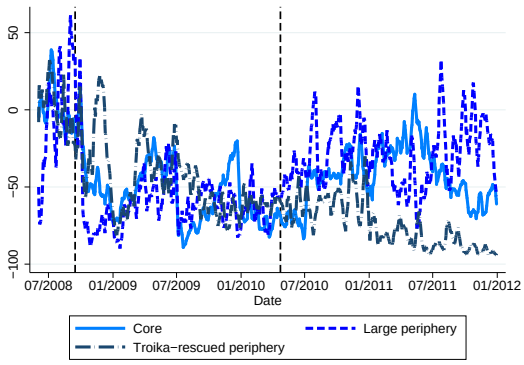
(a) Overnight-to-term ratio Core vs. periphery **(b) Overnight-to-term ratio Domestic vs. cross-border**

Notes: This figure shows the ratio of the aggregate daily lending amount in the overnight segment to the aggregate daily lending amount in the term segment for the period from September 7, 2009 to December 31, 2011. 'Term' lending relates to transactions with maturity larger than one week. In Subfigure (a), we show this ratio for interbank loans, where the borrowing bank is headquartered in either one of the 'core' or 'periphery' countries. 'Core' (solid blue line, left axis) refers to interbank transactions, where the (borrowing) bank is from either one of the following countries: Austria (AT), Germany (DE), Belgium (BE), the Netherlands (NL), France (FR), or Finland (FI), respectively. 'Periphery' (dashed blue line, left axis) relates to interbank transactions, where the (borrowing) bank is either from Italy (IT), Spain (ES), Greece (GR), Ireland (IE), or Portugal (PT). In Subfigure (b), we plot the overnight-to-term ratio for 'domestic' (solid blue line, left axis) and 'cross-border' (dashed blue line, left axis) interbank transactions. All series are expressed as percentage deviations from the mean value of each respective series during the pre-sovereign crisis period from September 7, 2009 to December 31, 2009. 'Crisis' denotes the mean of the periphery country CDS spreads (long-dashed red line, in logs on the right axis). All series (except 'Crisis') are smoothed with a 60-day moving average. The vertical dashed line corresponds to April 23, 2010, when Greece sought its financial support.

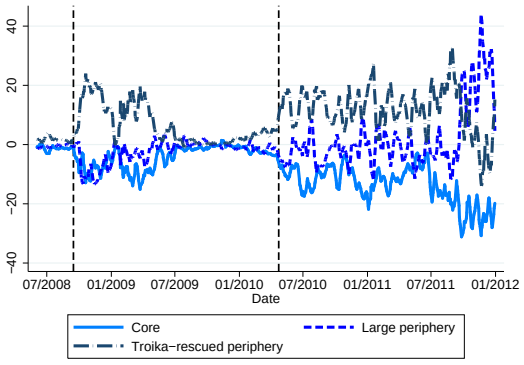
Figure 2:
Domestic vs. cross-border overnight interbank lending by country group



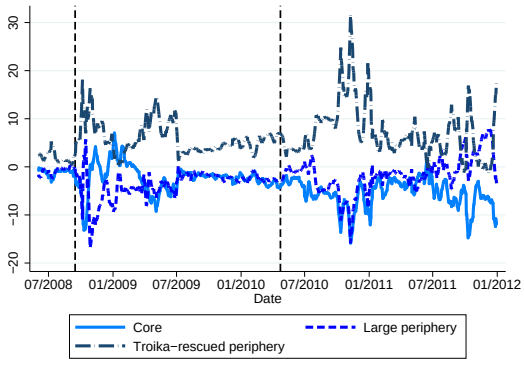
(a) Access: Domestic



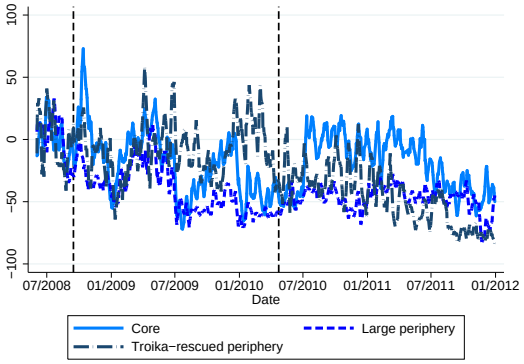
(b) Access: Cross-border



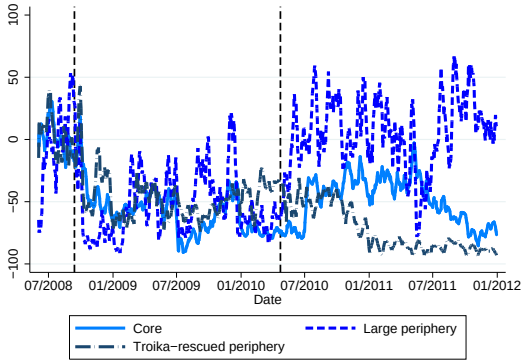
(c) Spread: Domestic



(d) Spread: Cross-border



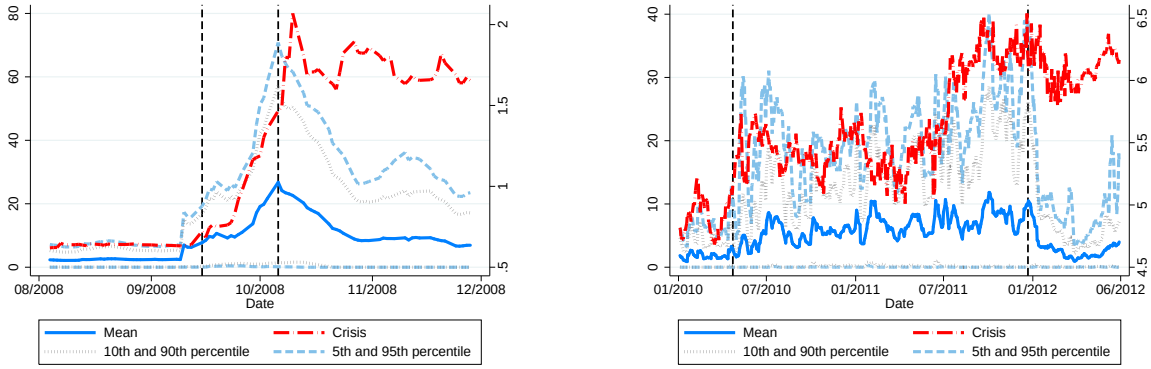
(e) Total amount: Domestic



(f) Total amount: Cross-border

Notes: This figure shows our overnight interbank lending data over the entire sample for both domestic and cross-border transactions decomposed into country groups. For each country group, 'Access' (loan availability) is the aggregate daily number of interbank transactions, 'Spread' refers to the country group's daily mean interest rate minus the (overall) daily mean interest rate, and 'Total amount' is the aggregate daily lending amount. 'Access' and 'Total amount' are expressed in percentage deviations from the mean of each respective series during the pre-Lehman period from August 1, 2008 to September 12, 2008. 'Spread' is expressed in basis points. 'Core' (solid blue line) refers to interbank transactions, where the (borrowing) bank is from Austria (AT), Germany (DE), Belgium (BE), the Netherlands (NL), France (FR) or Finland (FI). We label interbank transactions, where the (borrowing) bank is headquartered in Italy (IT) or Spain (ES) as 'Large periphery' (dashed blue line). 'Troika-rescued periphery' (long-dashed blue line) relates to interbank transactions, where the (borrowing) bank is headquartered in countries which have been rescued by the Troika, i.e. Greece (GR), Ireland (IE) or Portugal (PT). All series (except 'Crisis') are smoothed with a 10-day moving average. The first vertical dashed line corresponds to September 15, 2008, when Lehman Brothers filed for bankruptcy. The second vertical dashed line marks April 23, 2010, when Greece sought its financial support.

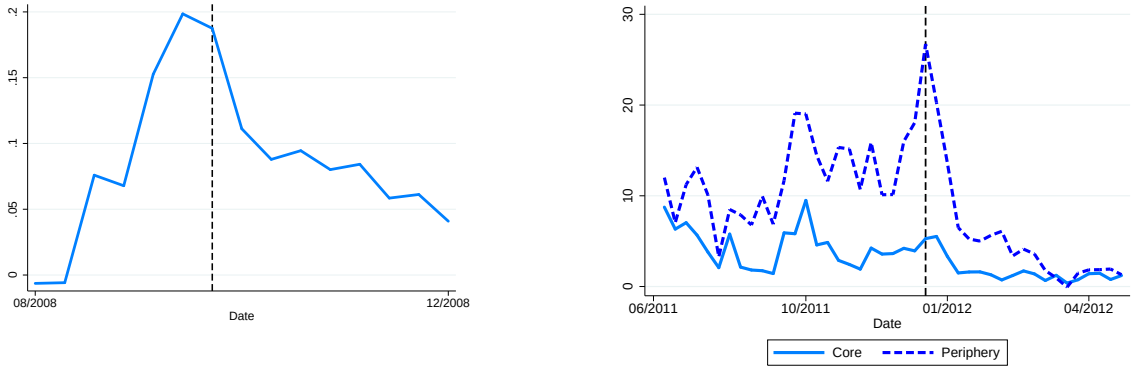
Figure 3 Panel A:
Price dispersion during the day: bank heterogeneity and crisis



(a) Lehman period **(b) Sovereign crisis period**

Notes: These subfigures show the daily mean (solid blue line, left axis), the 10th and 90th (dotted grey line, left axis) percentile, and the 5th and 95th (dashed blue line, left axis) of our price dispersion measure (in basis points). The price dispersion reflects, for any given borrower during the same day, the (volume-weighted) mean absolute deviation of interests rates from the minimum interest rate that she pays during the same day. Subfigure (a) covers the Lehman period from August 1, 2008 to December 31, 2008, Subfigure (b) refers to the sovereign crisis period from January 1, 2010 to April 30, 2012. In Subfigure (a), 'Crisis' refers to the three-month Euribor-OIS spread (long-dashed red line, in % on the right axis). The first vertical dashed line corresponds to September 15, 2008, when Lehman Brothers filed for bankruptcy, while the second dashed line marks October 8, 2008, when the Eurosystem announced its fixed-rate full allotment policy. In Subfigure (b), 'Crisis' refers to the mean of the periphery country CDS spreads (long-dashed red line, in logs on the right axis). The first vertical dashed line corresponds to April 23, 2010, when Greece sought its financial support. The second vertical dashed line marks December 8, 2012, when the Eurosystem promised its three-year long term refinancing operations. All series (except 'Crisis') in both subfigures are smoothed with a 10-day moving average.

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



(a) Fixed-rate full allotment effect **(b) Three-year LTRO effect**

Notes: This figure shows the estimated weekly time fixed effects from a linear regression of 'Price dispersion' on a set of bank fixed effects and week fixed effects. Subfigure (a), refers to the Lehman period from August 1, 2008 to December 31, 2008. Subfigure (b) depicts the sovereign crisis period from June 1, 2011 to April 30, 2012. In Subfigure (a), the vertical line refers to October 8, 2008, when the Eurosystem announced its fixed-rate full allotment policy while in Subfigure (b) it marks December 8, 2012, when the Eurosystem promised its three-year long term refinancing operations. 'Core' (solid blue line) and 'Periphery' (dashed blue line) are defined as in Figure 2. For further details see Panel A of this table.

Tables

Table 1 Panel A:
Summary statistics of overnight interbank lending data

Lehman period: August 18, 2008 – November 9, 2008, Daily frequency

	Mean	Median	Std.	10%	90%	Obs.
$\text{Access}_{i,j,t}$	5.16	0	22.13	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
$\text{Cross-border}_{i,j}$	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
$\text{Cross-border borrowing}_{j,t}$	19.94	0	30.73	0	78.85	4607
$\text{Cross-border borrowing ratio}_{j}$	0.08	0.01	0.29	0	0.15	4607
$\text{Price dispersion}_{j,t}$ during the day	11.32	5.17	15.21	0.36	31.68	4527
Crisis_{t}	1.12	0.83	0.51	0.64	1.81	4607

Sovereign crisis period: January 1, 2010 – December 31, 2011, Weekly frequency

	Mean	Median	Std.	10%	90%	Obs.
$\text{Access}_{i,j,t}$	11.87	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
$\text{Cross-border}_{i,j}$	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
$\text{Cross-border borrowing}_{j,t}$	14.43	0	25.68	0	57.94	11640
$\text{Cross-border borrowing ratio}_{j}$	0.03	0	0.08	0	0.09	11640
$\text{Price dispersion}_{j,t}$ during the day	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 of our overnight interbank lending data explained in Section 2. In the upper panel, we present the statistics for the Lehman period (August 18, 2008 to November 9, 2008, daily frequency), whereas the lower panel refers to the sovereign crisis period (January 1, 2010 to December 31, 2011, weekly frequency). 'Access' (extensive margin), 'Spread', and 'Volume' (intensive margins) are our dependent variables that we study at the bank-to-bank (i, j) level in Equation 1 and at the (borrower) bank (j) 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. Note that 'Price dispersion' is at daily frequency also during the sovereign crisis sample. 'Total amount' reflects the loan volume in EUR million, 'Volume' refers to the logarithm of 'Total amount'. We provide a summary of our variable definitions in Appendix A.

Table 1 Panel B:
Summary statistics of term interbank lending data

Lehman period: August 18, 2008 – November 9, 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
Cross-border term borrowing ratio$_j$	0.11	0.03	0.37	0.002	0.20	1459

Sovereign crisis period: January 1, 2010 – December 31, 2011, Weekly frequency

	Mean	Median	Std.	10%	90%	Obs.
Term access$_{j,t}$	40.43	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
Cross-border term borrowing ratio$_j$	0.04	0.01	0.08	0	0.11	5961

Notes: This table presents the descriptive statistics of the term lending data, where 'Term' refers to interbank transactions with maturity larger than one week. We study the term interbank lending segment at the (borrower) bank (j) level in Equation 2. For further details, see Section 2.1, Panel A of this table and Appendix A, respectively.

Table 2 Panel A:
Overnight interbank liquidity supply at the bank-to-bank level: Evidence for the Lehman 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)
$Crisis_t$	-1.98***				0.21				-0.06			
	(-11.75)				(0.19)				(-1.41)			
$Cross\text{-}border_{i,j}$	-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)	
$Crisis_t$*$Cross\text{-}border_{i,j}$			-1.08***	-0.85**			7.17***	6.31***			-0.18***	-0.09***
			(-3.22)	(-2.24)			(4.17)	(4.26)			(-3.28)	(-2.69)
Time fixed effects	No	Yes	Yes	-	No	Yes	Yes	-	No	Yes	Yes	-
Lender+Borrower fixed effects	No	Yes	Yes	-	No	Yes	Yes	-	No	Yes	Yes	-
Lender*Time fixed effects	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Borrower*Time fixed effects	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Lender-Borrower fixed effects	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
Lender-Borrower controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	332760	332760	332760	332760	13661	13661	13661	13661	13661	13661	13661	13661

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 1 using bank-to-bank (lender-borrower) level data from August 18, 2008 to November 9, 2008 at daily frequency. The dependent variable 'Access' (extensive margin) equals 100 if lender bank i grants an overnight loan to borrower bank j during day t, and zero if no loan is granted. The intensive margins credit are measured with the dependent variables 'Spread' (in basis points) and 'Volume' (in log EUR million). 'Crisis' refers to the three-month Euribor-OIS spread (in %). 'Lender-Borrower controls' refers to 'Relationship' (columns 1-3, 5-7, 9-11) and 'Crisis*Relationship' (columns 3-4, 7-8, 11-12). The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. Fixed effects are included ('Yes'), are not included ('No'), or are spanned by another set of fixed effects ('-'). We cluster robust standard errors at the bank-to-bank level and present robust t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 2 Panel B:
Overnight interbank liquidity 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)
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 borrower controls	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	12180	12180	12180	4607	4607	4607	4607	4607	4607	4607	4607

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 2 using (borrower) bank level data from August 18, 2008 to November 9, 2008 at daily frequency. The dependent variable 'Access' (extensive margin) equals 100 if bank j borrows in the overnight segment during day t, and zero otherwise. The intensive margins of credit are measured with the dependent variables 'Spread' (in basis points) and 'Volume' (in log EUR million). The dependent variable 'Cross-border borrowing' measures the daily cross-border borrowing volume (in % of daily total borrowing volume). 'Crisis' refers to the three-month Euribor-OIS spread (in %). 'Time-varying borrower controls' refer to 'Crisis*Borrowing concentration ratio' (columns 2-3, 4-5, 7-8, 10-11), and 'Crisis*Assets' and 'Crisis*Equity' (columns 3, 5, 8, 11). The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. Fixed effects are included ('Yes'), or are not included ('No'). We cluster robust standard errors at the bank level and present robust t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3:
Term interbank liquidity 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 borrower controls	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Observations	2139	2139	2139	1459	1459	1459	1459	1459

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 2 using (borrower) bank level data from August 18, 2008 to November 9, 2008 at daily frequency. The dependent variable 'Term Access' (extensive margin) equals 100 if bank j borrows in the term (maturity larger than one week) segment during day t, and zero otherwise. The intensive margins of credit are measured with the dependent variables 'Term Spread' (in basis points) and 'Term Volume' (in log EUR million). 'Crisis' refers to the three-month Euribor-OIS spread (in %). 'Time-varying borrower controls' refer to 'Crisis*Borrowing concentration ratio' (columns 2-3, 4-5, 7-8), and 'Crisis*Assets' and 'Crisis*Equity' (columns 3, 5, 8). The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. Fixed effects are included ('Yes'), or are not included ('No'). We cluster robust standard errors at the bank level and present robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 4 Panel A:
Overnight interbank liquidity 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)
Time fixed effects	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-
Lender+Borrower fixed effects	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-	No	Yes	Yes	Yes	-
Lender*Time fixed effects	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes
Borrower*Time fixed effects	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes
Lender-Borrower fixed effects	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes
Lender-Borrower controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	582712	582712	582712	582712	582712	60695	60695	60695	60695	60695	60695	60695	60695	60695	60695

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 1 using bank-to-bank (lender-borrower) level data from January 1, 2010 to December 31, 2011 at weekly frequency. The dependent variable 'Access' (extensive margin) equals 100 if lender bank i grants an overnight loan to borrower bank j during week t, and zero if no loan is granted. The intensive margins of credit are measured with the dependent variables 'Spread' (in basis points) and 'Volume' (in log EUR million). 'Crisis' refers to the sovereign CDS spread of the borrower's home country (in log basis points). 'Large periphery' equals the value one for all interbank transactions, where the borrower is headquartered in Spain or Italy, and zero otherwise. 'Troika-rescued periphery' equals the value one for all interbank transactions, where the borrower is from Greece, Ireland or Portugal, and zero otherwise. 'Lender-Borrower controls' refers to 'Relationship' (columns 1-4, 6-9, 11-14) and 'Crisis*Relationship' (columns 3-5, 8-10, 13-15). The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. Fixed effects are included ('Yes'), are not included ('No'), or are spanned by another set of fixed effects ('-'). We cluster robust standard errors at the bank-to-bank level and present robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 4 Panel B:
Overnight interbank liquidity 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			-15.57***				17.89***				-0.23				-4.91*	
$periphery_j$			(-3.77)				(7.19)				(-1.15)				(-1.83)	
$Crisis_{j,t}$*Cross-border		-6.67	-23.50	-13.56		-21.35**	-7.54	-9.34		-0.41	-0.58	-0.35		-7.12	-5.84	-5.44
borrowing $ratio_j$		(-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			0.07				-0.00				-0.00				0.11	
borrowing $ratio_j$*Large			(0.20)				(-0.02)				(-0.00)				(0.89)	
$periphery_j$																
$Crisis_{j,t}$*Cross-border			0.08				0.21				0.02				-0.28	
borrowing $ratio_j$*Troika-rescued			(0.25)				(1.32)				(1.14)				(-1.30)	
$periphery_j$																
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 borrower controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Observations	20800	20800	20800	20800	11640	11640	11640	11640	11640	11640	11640	11640	11640	11640	11640	11640

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 2 using (borrower) bank level data from January 1, 2010 to December 31, 2011 at weekly frequency. The dependent variable 'Access' (extensive margin) equals 100 if bank j borrows in the overnight segment during week t, and zero otherwise. The intensive margins of credit are measured with the dependent variables 'Spread' (in basis points) and 'Volume' (in log EUR million). The dependent variable 'Cross-border borrowing' measures the weekly cross-border borrowing volume (in % of weekly total borrowing volume). 'Crisis' refers to the sovereign CDS spread of the borrower's home country (in log basis points). 'Large periphery' equals the value one for all borrowers from Spain or Italy, and zero otherwise. 'Troika-rescued periphery' equals the value one for all borrowers from Greece, Ireland or Portugal, and zero otherwise. 'Time-varying borrower controls' refer to 'Crisis*Borrowing concentration ratio' (columns 2-4, 6-8, 10-12, 14-16), and 'Assets', 'Equity', 'Crisis*Assets' and 'Crisis*Equity' (columns 4, 8, 12, 16). The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. Fixed effects are included ('Yes'), or are not included ('No'). We cluster robust standard errors at the bank level and present robust t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 5:
Term interbank liquidity 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)	
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 borrower controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Observations	14744	14744	14744	14744	5961	5961	5961	5961	5961	5961	5961	5961

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 2 using (borrower) bank level data from January 1, 2010 to December 31, 2011 at weekly frequency. The dependent variable 'Term access' (extensive margin) equals 100 if bank j borrows in the term (maturity larger than one week) segment during week t, and zero otherwise. The intensive margins of borrowing are measured with the dependent variables 'Term spread' (in basis points) and 'Term volume' (in log EUR million). 'Crisis' refers to the sovereign CDS spread of the borrower's home country (in log basis points). 'Large periphery' equals the value one for all borrowers from Spain or Italy, and zero otherwise. 'Troika-rescued periphery' equals the value one for all borrowers from Greece, Ireland or Portugal, and zero otherwise. 'Time-varying borrower controls' refer to 'Crisis*Term borrowing concentration ratio (columns 2-4, 6-8, 10-12), and 'Assets', 'Equity', 'Crisis*Assets' and 'Crisis*Equity' (columns 4, 8, 12). The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. Fixed effects are included ('Yes'), or are not included ('No'). We cluster robust standard errors at the bank level and present robust t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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

	Price dispersion$_{j,t}$ for the same borrower during the same day						Price dispersion$_{j,t}$ for the same borrower during the same morning	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crisis$_t$	58.73***	56.07***	40.82***	58.17***	40.82***	42.51***	24.24***	23.11***
	(12.26)	(9.53)	(12.43)	(10.83)	(12.43)	(10.63)	(7.25)	(7.16)
Full Allotment$_t$	-46.79***	-43.62***	-32.03***	-46.40***	-32.03***	-31.93***	-9.96***	-9.41***
	(-9.27)	(-6.69)	(-9.97)	(-7.43)	(-9.97)	(-9.80)	(-3.45)	(-3.32)
Borrower fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Time fixed effects	No	No	Yes	No	Yes	Yes	Yes	Yes
Loan amount controls	No	No	No	Yes	Yes	Yes	Yes	Yes
Time-varying borrower controls	No	No	No	No	No	Yes	No	Yes
Observations	492	492	492	492	492	492	293	293

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 3 using (borrower) bank level data from August 18, 2008 to December 5, 2008 at daily frequency. The independent variable measures the 'Price dispersion' (in basis points) for the same borrower during the same day (or morning) in the overnight segment. 'Price dispersion' is computed on the basis of interest rates from our bank-to-bank loan level data that we clean in some specifications by lender*time fixed effects ('Lender*Time fixed effects' = Yes) and loan amounts ('Loan amount controls' = Yes) before aggregation at the borrower-day (or borrower-morning) level. In the regressions of this panel we include only observations of 'Price dispersion' that exceed the 90th percentile (at each given day or morning). Borrower fixed effects are included in the regression analysis. 'Crisis' denotes the three-month Euribor-OIS spread (in %). 'Full Allotment' equals the value one on all days as of October 8, 2008, when the Eurosystem announced the fixed-rate full allotment policy, and zero on any other day. 'Time-varying borrower controls' refer to 'Crisis*Cross-border borrowing ratio', 'Crisis*Borrowing concentration ratio', 'Crisis*Assets' and 'Crisis*Equity'. The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. We cluster robust standard errors at the bank level and present robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

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

	Percentiles of Price dispersion$_{j,t}$ for the same borrower during the same morning											
	Last 4 weeks before Lehman			First 2 weeks after Lehman			3rd to 4th week after Lehman			5th to 12th 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$_{j,t}$	6.10	6.02	4.10	3.13	8.56**	5.02	3.21	8.26***	12.33***	10.84***	16.48***	26.10***
	(1.53)	(1.12)	(0.48)	(1.37)	(2.50)	(0.97)	(1.02)	(2.78)	(2.80)	(8.65)	(7.15)	(7.66)
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
Time-varying borrower controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	920	920	920	526	526	526	416	416	416	1437	1437	1437

Notes: This table shows the estimated coefficients of the bootstrapped quantile regression models in Equation 4 using (borrower) bank level data from August 18, 2008 to December 5, 2008 at daily frequency. On September 15, 2008, Lehman Brothers filed for bankruptcy. The independent variable measures the 'Price dispersion' (in basis points) for the same borrower during the same morning in the overnight segment. 'Borrower risk' refers to the average spread paid by each borrower on the previous day in the overnight segment as a proxy for borrower risk (expressed in %). 'Price dispersion' is computed on the basis of interest rates from our bank-to-bank loan level data that we clean in all specifications by lender*time fixed effects ('Lender*Time fixed effects' = Yes) and loan amounts ('Loan amount controls' = Yes) before aggregation at the borrower-day (or borrower-morning) level. Price dispersion is cleaned by 'Time fixed effects' in a separate preliminary regression before inclusion in the quantile regressions. 'Time-varying borrower controls' refer to 'Assets', 'Equity', 'Number of lenders', 'Volume', 'Cross-border borrowing ratio' and 'Borrowing concentration ratio'. The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. We present t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 6 Panel C:
Bank-to-bank heterogeneity of price dispersion: Evidence on cross-border for the Lehman period

	$\text{Spread}_{i,j,t}$ during the morning							
	Last 4 weeks before Lehman		First 2 weeks after Lehman		3rd to 4th week after Lehman		5th to 12th 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	16.16***	14.95***
	(0.63)	(1.16)	(5.39)	(4.08)	(2.68)	(1.57)	(5.77)	(5.26)
$\text{Loan amount}_{i,j,t}$		-0.33**		1.92***		6.79***		3.62***
		(-2.49)		(5.39)		(5.30)		(4.68)
Lender*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borrower*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying lender-borrower controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2234	2234	1506	1506	1327	1327	4129	4129

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 5 using bank-to-bank (lender-borrower) level data from August 18, 2008 to December 5, 2008 at daily frequency. The dependent variable 'Spread' measures the price of overnight loans (in basis points) from lender i to borrower j granted during the morning of day t. 'Time-varying lender-borrower controls' include 'Cross-border*Assets', 'Cross-border*Equity', 'Relationship', 'Relationship*Assets' and 'Relationship*Equity'. The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. We cluster robust standard errors at the bank-to-bank level and present robust t-statistics in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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

	Price dispersion$_{j,t}$ for the same borrower during the same day							Price dispersion$_{j,t}$ for the same borrower during the same morning	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crisis$_{j,t}$	4.85***	15.53***	5.60**	10.07***	12.32***	8.35***	7.28***	8.50***	7.17***
	(7.36)	(7.07)	(2.17)	(11.30)	(13.33)	(8.91)	(10.35)	(8.26)	(8.19)
Crisis$_{j,t}$*Large periphery$_j$			9.04**						
			(2.22)						
Crisis$_{j,t}$*Troika-rescued periphery$_j$			12.91***						
			(4.02)						
LTRO$_t$	-14.25***	-20.84***	-13.92***	-12.13***	-16.68***	-7.14***	-6.09***	-6.92***	-5.79**
	(-11.78)	(-11.92)	(-7.83)	(-11.16)	(-10.78)	(-5.41)	(-3.04)	(-4.03)	(-2.33)
LTRO$_t$*Large periphery$_j$			-6.69**						
			(-2.56)						
Borrower fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lender*Time fixed effects	No	No	No	Yes	No	Yes	Yes	Yes	Yes
Loan amount controls	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Time-varying borrower control	No	No	No	No	No	No	Yes	No	Yes
Observations	2085	2085	2085	2085	2085	2085	2085	1567	1567

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 3 using (borrower) bank level data from January 1, 2010 to April 29, 2012 at daily frequency. The independent variable measures the 'Price dispersion' (in basis points) for the same borrower during the same day (or morning). 'Price dispersion' is computed on the basis of interest rates from our bank-to-bank loan level data that we clean in some specifications by lender*time fixed effects ('Lender*Time fixed effects' = Yes) and loan amounts ('Loan amount controls' = Yes) before aggregation at the borrower-day (or borrower-morning) level. In the regressions of this panel we include only observations of 'Price dispersion' that exceed the 90th percentile (at each given day or morning). Borrower fixed effects are included in the regression analysis. 'Crisis' denotes log sovereign CDS spread of the borrower's home country (in log basis points). 'LTRO' equals the value one on all days as of December 8, 2012, when the Eurosystem promised its three-year long term refinancing operations, and zero on any other day. 'Time-varying borrower controls' refer to 'Crisis*Cross-border borrowing ratio', 'Crisis*Borrowing concentration ratio', 'Crisis*Assets' and 'Crisis*Equity'. The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. We cluster robust standard errors at the bank level and present robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

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

	Percentiles of Price dispersion$_{j,t}$ for the same borrower 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 shows the estimated coefficients of the bootstrapped quantile regression models in Equation 4 using (borrower) bank level data from January 1, 2010 to April 29, 2012 at daily frequency. The independent variable measures the 'Price dispersion' (in basis points) for the same borrower during the same morning in the overnight segment. 'Borrower risk' refers to the average spread paid by each borrower on the previous day in the overnight segment as a proxy for borrower risk (expressed in %). 'Price dispersion' is computed on the basis of interest rates from our bank-to-bank loan level data that we clean in all specifications by lender*time fixed effects ('Lender*Time fixed effects' = Yes) and loan amounts ('Loan amount controls' = Yes) before aggregation at the borrower-day (or borrower-morning) level. Price dispersion is cleaned by 'Time fixed effects' in a separate preliminary regression before inclusion in the quantile regressions. 'Borrower controls' refer to 'Assets', 'Equity', 'Number of lenders', 'Volume', 'Cross-border borrowing ratio' and 'Borrowing concentration ratio'. The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. We present t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 7 Panel C:
Bank-pair heterogeneity of price dispersion: Evidence on cross-border 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)				
Loan amount$_{i,j,t}$		0.45***		-0.64***		-2.37***		-0.49**
		(2.89)		(-3.20)		(-4.22)		(-2.56)
Lender*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borrower*Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying lender-borrower controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1879	1879	12663	12663	3901	3901	1390	1390

Notes: This table shows the ordinary least squares estimates of the linear regression models in Equation 5 using bank-to-bank (lender-borrower) level data from August 18, 2008 to December 5, 2008 at weekly frequency. The dependent variable 'Spread' measures the average price of overnight loans (in basis points) from lender i to borrower j granted during the mornings of week t. 'Time-varying lender-borrower controls' include 'Cross-border*Assets', 'Cross-border*Equity', 'Relationship', 'Relationship*Assets' and 'Relationship*Equity'. The definition of all dependent and independent variables is provided in Appendix A and summary statistics can be found in Table 1. Where possible a constant is included but its estimate is not shown to avoid cluttering. We cluster robust standard errors at the bank-to-bank level and present robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Appendix A: Definition of Variables

Panel A: Definition of dependent variables

Variable	Definition
$\text{Access}_{i,j,t}$	Binary variable that equals the value 100 if lender bank i engages in at least one overnight interbank transaction with borrower bank j during day (or week) t, and zero otherwise.
$\text{Spread}_{i,j,t}$	Difference (in basis points) between the (volume-weighted) interest rate that borrower j pays to lender i for overnight interbank transactions during day (or week) t and the (volume-weighted) interest rate of all overnight interbank transactions during the same day (or week) t.
$\text{Volume}_{i,j,t}$	Logarithm of the aggregate overnight interbank lending 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 engages in at least one overnight interbank transaction 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 her overnight interbank transactions during day (or week) t and the (volume-weighted) interest rate of all overnight interbank transactions during the same day (or week) t.
$\text{Volume}_{j,t}$	Logarithm of the aggregate overnight interbank lending amount (in EUR million) that is provided to borrower j during day (or week) t.
Cross-border $\text{borrowing}_{j,t}$	Aggregate overnight interbank lending amount that is provided to borrower j by foreign lenders during day (or week) t in % of her aggregate overnight interbank lending amounts received during the same day (or week) t.
Term $\text{access}_{j,t}$	Binary variable that equals the value 100 if borrower j engages in at least one term interbank transaction during day (or week) t, and zero otherwise. 'Term' refers to interbank transactions with maturity higher than one week.
Term $\text{spread}_{j,t}$	Mean of the (four) maturity bucket 'spreads'. 'Spread' in this context corresponds to the difference (in basis points) between the (volume-weighted) interest rate that borrower j pays for her term interbank transactions in the respective maturity bucket during the day (or week) t and the (volume-weighted) interest rate of all term interbank transactions in the respective bucket during the same day (or week) t.
Term $\text{volume}_{j,t}$	Logarithm of aggregate term interbank lending amount (in EUR million) that is provided to borrower j during day (or week) t.
Price $\text{dispersion}_{j,t}$	Volume-weighted mean absolute deviation of interests rates that borrower j pays for all her overnight interbank transactions during the same morning (or day) from the minimum rate that she pays during the same morning (or day) t. 'Morning' (or 'day') relates to interbank transactions conducted until noon (or 6pm).

Notes: This table provides a summary of 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 overnight interbank liquidity supply, observed only if $\text{Access}_{i,j,t}$=1 or $\text{Access}_{j,t}$=1, respectively. 'Term' refers to interbank transactions with maturity higher than one week. 'Term spread' is the mean of the average spread paid in four different term buckets. The first bucket 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.

Panel B:
Definition of independent variables

Variable name	Definition
Crisis_t	Three-month Euribor-OIS spread (in %) on any given day t.
$\text{Crisis}_{j,t}$	Five-day moving average of the logarithm of the five-year sovereign CDS spread (in basis points) on any given week t of the country where borrower j is headquartered.
Full Allotment_t	Binary variable that equals the value one as of October 8, 2008, when the Eurosystem announced the fixed-rate full allotment policy and zero on any other day.
LTRO_t	Binary variable that equals the value one as of December 8, 2011, when the Eurosystem announced her three-year long term refinancing operations and zero on any other day.
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.
$\text{Cross-border borrowing ratio}_j$	Aggregate overnight interbank lending amount that is provided to borrower j from foreign lenders during a reference period as a share of her total assets.
$\text{Term cross-border borrowing ratio}_j$	Measures the aggregate term interbank lending amount that is provided to borrower j from cross-border during a reference period as a share of her total assets.

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

Appendix B: 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.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 any further decomposition such as domestic vs cross-border and core vs. periphery.

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.