



Lending-of-last-resort is as lending-of-last-resort does: Central bank liquidity provision and interbank market functioning in the euro area[☆]



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ABSTRACT

This paper investigates the impact of ample liquidity provision by the European Central Bank on the functioning of the overnight unsecured interbank market from 2008 to 2014. We use novel data on interbank transactions derived from TARGET2, the main euro area payment system. To identify exogenous shocks to central bank liquidity, we exploit the timing of ECB liquidity operations and use a simple structural vector auto-regression framework. We argue that the ECB acted as a de facto lender-of-last-resort to the euro area banking system and identify two main effects of central bank liquidity provision on interbank markets. First, central bank liquidity replaces the demand for liquidity in the interbank market, especially during the financial crisis (2008–2010). Second, it increases the supply of liquidity in the interbank market in stressed countries (Greece, Italy and Spain) during the sovereign debt crisis (2011–2013).

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1. Introduction

The task of a Lender Of Last Resort (LOLR) is to provide liquidity to the banking system in case of a systemic liquidity crisis. The operational framework of the ECB and the European System of Central Banks does not contain any formal reference to the LOLR function. However, in this paper we argue that by providing unlimited liquidity against good collateral, and at above normal rates, since October 2008, the ECB acted as a de facto LOLR for the whole banking system of the euro area.

We document how such de facto “lending-of-last-resort” to the banking system impacts the unsecured overnight interbank market, which is the place where banks trade central bank liquidity

(reserves). To do so, we exploit a novel and comprehensive data set on overnight unsecured interbank transactions in the euro area from 2008 to 2014. Our main finding is that the impact of the ECB’s liquidity provision on interbank market activity is heterogeneous: It affects the demand and supply in the private marketplace differently across space (countries) and time (financial versus sovereign debt crisis). Three sets of results stand out.

First, the increase in central bank liquidity provision replaced the demand for reserves in the overnight unsecured interbank market, especially during the global financial crisis period (2008–2010). The ECB “took over” the liquidity provision role of the interbank market. Given that interbank markets came under severe stress in the aftermath of the Lehman bankruptcy, the ECB indeed acted as a lender-of-last-resort to the euro area banking system.

Second, the provision of central bank liquidity not only “replaced” the interbank market, it also stimulated the supply of liquidity, especially to banks located in stressed countries (Greece, Spain and Italy) during the European sovereign debt crisis (2011–2013). Reinsuring the banking system therefore can have important extra benefits as it can stimulate bank lending (at least in interbank markets).

Third, the impact of central bank liquidity provision was highly uneven across the euro area. This is both a blessing and a curse. The ECB’s liquidity provision was able to counter-act the capital flow reversal which took place during the sovereign debt crisis when interbank markets became fragmented along the national lines. But it shows how the ECB’s actions, which are by design uniform across the euro area, played out differently in different parts

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of the euro area. For example, the German banking system witnessed a considerable inflow of liquidity, almost completely crowding out demand by German banks. This led to a low volume of trading and, in particular, to low interest rates in the interbank market.

Examining the interplay between central bank liquidity provision and interbank market activity presents a number of empirical challenges. The vast majority of interbank transactions take place in over-the-counter markets. There is no centralized record-keeping of transactions and of the resulting volumes and interest rates. In the euro area, an often-quoted overnight rate, the EONIA, which also acts as the euro area reference rate, is based on daily aggregated lending information reported by a selected group of large banks. In the presence of market malfunctioning, there is no guarantee that the interbank activity of this group of banks is representative for either the entire euro area or individual euro area countries. We deal with this challenge by reconstructing overnight loans from the Eurosystem payment system (TARGET2), employing a *Furfine* (1999, 2001)-type algorithm. In particular, we are able to identify the countries in which lenders and borrowers are located. We construct our dataset based on the location of borrowers and consider four countries, Germany, Greece, Italy and Spain, as well as the euro area as a whole.

Another challenge is that both central bank liquidity provision and interbank market activity are endogenous. On the one hand, the price and quantity of liquidity in the interbank market depends on the liquidity needs of the banking system (which is roughly given by reserve requirements and banknotes in circulation, and is inelastic in the short term) and on the amount borrowed by banks from the central bank. On the other hand, market conditions affect central bank liquidity provision. If banks find it difficult or expensive to borrow in the market, they will borrow from the central bank.

Our analysis deals with the endogeneity challenge by employing a structural vector-autoregression (VAR) framework, which allows establishing causality in the presence of dynamic feedbacks. The key to identification is that in-between central bank liquidity providing operations, which happen once a week, the aggregate amount of reserves in the system is fixed and unaffected by interbank trading while the overnight interbank market continues to be active.

One final complication is that the degree to which banks are able to borrow in the interbank market as well as banks' demand for central bank funding both depend on the degree of stress in the banking sector. Under stress, potential lenders in the interbank market may be less willing to supply liquidity either because of concerns about counterparty risk or because they want to keep the liquidity for themselves as a precaution. Under stress, banks that need liquidity may therefore borrow from the central bank. We control for stress in two ways: 1) by including a measure of bank risk to control for the level of stress, and 2) by conducting our VAR analysis at the country level and for different time periods, which allows a differential impact of the LOLR on interbank market activity depending on stress (which varies across countries and time).

We conduct a series of robustness checks, including examining alternative measures of bank risk, and analyzing domestic and cross-border interbank activity separately. We also check whether our identifying assumption that innovations to central bank liquidity are orthogonal to current interbank variables is plausible by employing market forecasts of the liquidity take-up in Eurosystem liquidity operations using data from Thomson Reuters. This is an interesting exercise in its own right, as to our knowledge, this data has not been exploited in the academic literature so far.

There are four strands of literature that relate to our paper: on the implications of the LOLR function, the interplay between

sovereign and bank risk during the euro area sovereign debt crisis, the (mal)functioning of interbank markets during periods of stress, and the empirical analysis of payment systems transaction data.

Acharya and Tuckman (2014) raise concerns that an indirect effect of the LOLR function is to lower incentives for banks to reduce their exposure to illiquid assets. This may have the unintended consequence of engaging banks in excessive illiquid leverage, making future liquidity crisis more likely. This intuition seems to be partly borne out by empirical evidence. *Drechsler et al.* (2014) examine what kind of banks borrow from the ECB and what type of collateral they pledge. They find that as of the start of the sovereign debt crisis in May 2010, riskier banks borrow more and pledge riskier collateral. Moreover, weakly capitalized banks increase their holdings of risky assets while, at the same time, borrowing from the ECB. The study concludes that these findings are at odds with classic LOLR function. *Acharya et al.* (2014b) examine financial conditions of dealers that participated in two LOLR facilities of the Federal Reserve, the Term Securities Lending Facility and the Primary Dealer Credit Facility. They document that dealers with weaker financial conditions (more levered and with lower equity returns prior to the outbreak of the crisis) were more likely to make use of the LOLR programs. Dealers with less liquid collateral also tended to borrow more. They conclude that both solvency and illiquidity conditions play a role in LOLR utilization, and that there may be an interaction between the two conditions.

Focusing on the interplay between sovereign and bank risk, *Acharya et al.* (2014a) examine the feedback effects between sovereign credit risk and bank bailouts using credit default swap information. They find that, following bank bailouts, sovereign risk materialized in the Eurozone starting mid-2011. *Acharya and Steffen* (2015) find evidence that European banks designed investment strategies from 2007 to 2012 based on the purchasing of peripheral bonds through short-term debt financing. They conclude that moral hazard played a key role, in particular for large banks with ample access to central bank funding.

Several studies have also analyzed the possible malfunctioning of the interbank market, both theoretically and empirically. On the theory side, *Freixas and Holthausen* (2005) study interbank markets in an international context. They find that cross-border interbank trade can break down due to imperfect information that lenders have about borrowers from abroad. *Heider et al.* (2015) analyze the effect of asymmetric information and counterparty credit risk on the functioning of the interbank market. They show that when information asymmetry about counterparty risk is large, interbank market trade can break down due to a withdrawal of supply and banks hoard liquidity to self-insure against liquidity shocks. A number of recent studies analyze empirically the impact of the recent financial crisis on certain domestic interbank markets. *Afonso et al.* (2011) examine the unsecured overnight market in the United States and show that market activity shrinks considerably after the bankruptcy of Lehman Brothers, but it does not collapse completely. The shrinking appears to be caused mostly by a withdrawal of supply. *Angelini et al.* (2011) use data from the Italian e-MID market to show that under stress, the Italian domestic interbank market becomes sensitive to bank-specific characteristics: banks with a lower credit rating, or those holding less capital, face higher rates in the unsecured market. *Brunetti et al.* (2011) use the same data to examine whether central bank interventions improved liquidity in the interbank market. They find that public injections of liquidity increases overall uncertainty, as measured by higher market volatility and higher spreads. According to their findings, asymmetric information is not mitigated by ECB interventions. *Acharya and Merrouche* (2013) use information about the reserve accounts of large UK settlement banks and find evidence of precautionary hoarding of liquidity.

Finally, our paper is also linked to the literature exploiting payment system data. Frutos et al. (2016) and Arciero et al. (2016) provide a first description of the functioning of the euro area overnight interbank loan market during the financial crisis on the basis of TARGET2 data. They find that cross-border transactions fell by a third following the Lehman bankruptcy. Interbank lending data based on TARGET2 transactions have been used to track the overall evolution of money markets over time from a financial stability perspective. Gabrieli and Georg (2014) find evidence that, after the Lehman bankruptcy, only the term segment of the market froze, as banks switched from longer maturities (1 to 12 months) to the shortest possible one (overnight). Garcia-de-Andoain et al. (2014) suggest that the interbank market continued to be integrated after the Lehman bankruptcy and throughout 2009, but that it showed strong signs of fragmentation at the peak of the sovereign debt crisis in the second half of 2011.

The remainder of the paper is organized as follows. Section 2 reviews the Eurosystem framework for liquidity provision and discusses its relation to the lender-of-last-resort functions. Section 3 describes the data. Section 4 presents our identification and econometric strategy. Section 5 contains the results. Section 6 offers an economic interpretation to our econometric results. Section 7 presents robustness exercises. Section 8 concludes.

2. LOLR and the Eurosystem framework for liquidity provision

The words Lender of Last Resort (LOLR) do not appear in any documentation describing the functioning of the Eurosystem. Still, the Eurosystem, as the monetary authority of the euro area, is in charge of managing the liquidity of the banking system. In this section, we discuss to what extent the function of LOLR is implicitly embedded in the operational framework of the Eurosystem.

It is useful to start by distinguishing between two types of liquidity injections: emergency liquidity assistance (ELA) and standard liquidity provision via monetary policy operations.

ELA is the exceptional provision of central bank liquidity to a solvent euro area credit institution facing temporary liquidity problems. It is provided by the competent national central bank of the Eurosystem. Even though the Governing Council has the authority to restrict the use of these operations, a key characteristic of ELA is that its responsibility lies with the national central bank. In particular, any costs and risks arising from ELA operations are incurred by the national central bank itself. ELA does satisfy most of the general principles set up by Bagehot (1873) for a LOLR, that is lend freely to solvent institutions at a high rate. One exception is the required collateral, which for ELA can be of lower quality than for standard liquidity operations. It can be considered a LOLR instrument for individual banks.

In this paper, we are interested in the role that the ECB has in the case of systemic liquidity crises. Since its inception, the ECB has in fact assumed full responsibility for providing aggregate liquidity. This responsibility is intrinsically linked to the monetary policy function and its operational framework (see Padoa-Schioppa, 1999). To fully appreciate how the LOLR function relates to the ECB, it is therefore necessary to review its operational framework.¹

The operational framework of the Eurosystem rests on three main building blocks: open market operations, standing facilities and minimum reserve requirements for credit institutions. Unlike in the US, where open market operations are conducted by buying Treasury bonds, the ECB conducts its operations mainly through repurchase agreements (repos). Repos are loans that the ECB grants to its counterparties, against suitable collateral and at the rate in

its main refinancing operations (MRO). They are generally conducted at weekly frequency with a maturity of one week and less often with a maturity of three months. Since the start of the crisis, the ECB has extended the maturity of its operations up to four years.

Standing facilities aim to smooth overnight liquidity shocks to individual banks and provide a corridor that bounds the overnight interest rate. Banks can deposit their excess reserves at the deposit facility (whose remuneration rate provides a floor for the market rates) and borrow reserves from the marginal lending facility (whose rate provides a ceiling for the market rates). There are no limits for how much a bank can deposit with the ECB, while the amount it can borrow from the marginal lending facility is limited only by the available collateral.

The equivalent to the ECB's marginal lending facility in the U.S. is the discount window, which provides banks access to short-term loans at the prevailing interest rate (or discount rate). Contrary to the ECB, the Fed charges three different interest rates to depository institutions at the discount window – for primary, secondary and seasonal credit. The rate paid by banks for primary credit is lower than the rate paid for secondary or seasonal funding (for cases of temporary liquidity needs or small institutions in sectors such as agriculture, respectively).² At the Eurosystem, a comparable monetary policy tool to provide liquidity to banks facing temporary tensions at a higher-than-normal price would be ELA.

The final important element of the ECB operational framework is the need for banks to hold a minimum amount of reserves. Credit institutions are required to hold reserves with the ECB, whose amount is determined in relation to their customer deposits. The compliance with the reserve requirement is calculated on the basis of the institutions' average daily reserve holdings over about a month (referred to as "maintenance period"). Its main function is to create a structural liquidity shortage in the market, which allows the ECB to control and stabilize money market rates. One important feature of minimum reserves is that only the required amount is remunerated at the MRO rate. Amounts in excess are not remunerated, so that banks have incentives to trade them on the market or park them on the deposit facility where they are remunerated at a rate below the MRO rate. Since 2008, also the US Federal Reserve has introduced a corridor system and is paying interest rates on excess reserve balances.

The ECB operational framework has been modified in two important ways since the start of the financial crisis in 2008. One change was the move to a fixed rate full allotment (FRFA) policy. While during normal times the ECB allotted only the amount of liquidity needed to cover the structural liquidity deficit of the banking system, since October 2008 banks can obtain all the liquidity they wish for (provided they have suitable collateral) at the prevailing MRO rate. The second important change was a widening of the eligible collateral, which accompanied the introduction of the FRFA. The widening of the collateral was aimed at increasing the liquidity supplied to the market and at mitigating the destabilizing effects of short-term funding runs and fire-sales related to a deterioration of asset liquidity.

With the introduction of FRFA, the amount of central bank liquidity became endogenously determined by the banks' needs. During periods of high financial stress, the demand for liquidity increased. One side effect was that the total central bank liquidity outstanding exceeded the amount needed to cover the minimum reserve requirements, pushing banks to move their excess reserves to the deposit facility and therefore driving overnight market rates to the floor of the ECB interest rate corridor.

¹ For more details, see Bindseil (2014). In Chapter 14, he also distinguishes between the LOLR to individual banks and the LOLR to the banking system as a whole.

² See Monetary Policy and Policy Tools, Board of Governors of the Federal Reserve System (2016), http://www.federalreserve.gov/monetarypolicy/bst_lendingdepository.htm.

A few points are worth noting in relation to the LOLR function of the ECB. First, with the FRFA the ECB did lend freely to any bank with available collateral, making sure the system was not short of liquidity. While still in place, the ECB marginal lending facility – the equivalent of the Fed’s discount window – was made redundant by the FRFA policy: since banks could borrow unlimited amounts of liquidity at the weekly refinancing operations, the use of the marginal lending facility was extremely limited thereafter. Second, the large amount of excess liquidity in the system brought the overnight market rates close to the deposit rate. Therefore, banks with market access could refinance themselves in the market at a discount compared to the MRO rate. However, illiquid banks that lost market access had to rely on ECB funding and therefore pay the higher (MRO) rate. Third, the ECB did continue to lend only to solvent banks and against appropriate collateral. Even though the collateral base was expanded, such a widening was accompanied by proper risk management measures, such as haircuts to mitigate the increase of the risk profile of the ECB. Banks short of financially sound collateral had to move to the ELA, paying higher rates for the central bank liquidity and shifting the associated credit risk to the balance sheet of the corresponding national central bank.

So, even though the ECB statute does not explicitly regulate its function as LOLR, in practice its operational framework has built-in mechanisms which have allowed the ECB to serve as LOLR to its banking system.

3. Data

Our sample dataset combines three sources of information: confidential TARGET2 data, measures of bank risk, and aggregate Eurosystem excess liquidity. Our data starts on October 15, 2008 (the beginning of the FRFA regime) and runs until June 10, 2014.

We use a Furfine-type algorithm that extracts interbank payments transactions in the TARGET2 system and uses them to construct overnight loans.³ This algorithm matches transactions between banks on a specific date with a reverse transaction at a later date, accrued by a plausible interest rate. The implementation relies on several assumptions about, *inter alia*, minimum loan values, plausible interest rates and the maximum reliable duration. We rely on the dataset from Frutos et al. (2016) who focus exclusively on overnight transactions. This allows them to impose very mild *ex ante* restrictions on the plausible interest rates, a feature which is particularly appealing during periods of high stress (such as those witnessed during the Lehman bankruptcy or the euro area sovereign crisis).⁴ The application of the Furfine algorithm to the TARGET2 data results in 94% of all overnight loans being correctly matched.⁵ Only 1% of overnight loans are wrongly paired (type I error or false positives). In addition, 6% of overnight loans are not identified, however the sources of the errors are known.⁶ The success of applying a Furfine algorithm to TARGET2 data at the Eu-

rosystem comes from knowing the ultimate originator and beneficiary of a transaction.⁷ In TARGET2 data, transactions conducted on behalf of a bank’s correspondents are identified. We can therefore construct our dataset based on the final originator and beneficiary of the payment carried out in TARGET2. This also means that we are able to correctly assign a country of residence to the lender and borrower in every overnight loan.⁸

We focus on borrowing banks and group them according to the country of residence. For each country, we then compute the daily volume-weighted average borrowing interest rate (in percent) as well as the total daily borrowing (in EUR bn). We also calculate total volume and average borrowing rate for the entire Eurozone, which we use as a benchmark in our econometric model. We then restrict our sample to banks located in Germany, Greece, Spain and Italy and conduct country-specific analysis. Figs. 1 and 2 show the interest rate and volume of overnight unsecured interbank loans constructed from TARGET2 payments data.

Our dataset contains the total daily excess liquidity outstanding at the Eurosystem. Excess liquidity reflects how much Eurosystem liquidity provision exceeds the needs of the banking system and is inherently related to the LOLR function of providing liquidity reinsurance to the banking system in crisis times. Excess liquidity is created whenever private transactions between banks stop and are instead carried out via the balance-sheet of the Eurosystem. Transacting via the central bank limits counterparty risk as a bank has its central bank as a counterparty instead of a private bank.

The time series behavior of excess liquidity is plotted in Fig. 3. The large increases following the 3-year long-term refinancing operations at the beginning of 2012 are clearly visible and are taken into account in our empirical specification. When conducting country-specific analysis, we consider interbank rates and volumes at the country level and excess liquidity at the euro area level. This is because central bank money flows freely between banks located in different countries as a consequence of cross-border payments and it would not be meaningful to consider excess liquidity at the country level.

To control for bank risk, we use credit default swaps (CDSs) data from Credit Market Analysis (in our benchmark VAR specification). In two separate robustness checks, we use Expected Default Frequencies (EDFs) from KMV Moody’s and sovereign CDS data instead of bank CDS data. To construct a country-level index of bank risk based on CDS data, we weigh CDS of banks trading in the interbank market in a given week by the volume they trade. To construct a country-level index of bank risk based on EDF data, we obtain from KMV Moody’s the expected default frequencies over one year of a representative sample of banks, with their EDFs weighted by total assets.

Further details on the construction of our dataset are contained in Table 1 and in the Appendix. The summary statistics for all variables and countries are presented in Table 2. In our estimations, we split the sample into two sub-periods (before and after 19th July 2011; see Section 4); we therefore present the statistics for each subsample separately. In addition, Tables 3 and 4 show summary statistics for interbank activity distinguishing between domestic (Table 3) and cross-border (Table 4) transactions. We analyze domestic and cross-border interbank activity in a robustness check in Section 7.3.

³ Long term maturities in the interbank market are also a source of private funding. According to the ECB Money Market Survey, a large fraction of interbank market funding is overnight. Therefore in this paper we simplify private funding to be solely from the overnight market. We also abstract from secured funding as information about that market segment is very limited.

⁴ For a detailed explanation of the methodology see Frutos et al. (2016).

⁵ Results from the Furfine algorithm are benchmarked against the official universe of domestic overnight money market loans in MID – Mercado Interbancario de Depósitos maintained at Banco de España.

⁶ Reasons for this discrepancy are attributed to specificities of the Banco de España post-trading structure which are aimed at liquidity efficiency (*i.e.* netting out of transactions that take place within 30 min among the same counterparties). In addition, the Furfine algorithm does not search for overnight loans that are less than 1 mill. EUR and that are not lent on a round lot amount (*i.e.* 100,000 EUR increments). These reasons for error are not directly related to the accuracy of the algorithm as such.

⁷ This is in contrast to the U.S. Fedwire data where it is not at all clear whether a bank sending the payment over Fedwire is itself originating the payment or whether one of that bank’s correspondents is originating the payment. Similarly, the identity of the ultimate beneficiary of the payment cannot be guaranteed in the Fedwire data. See Armantier and Copeland (2015) for details on the issues arising when the Furfine algorithm is applied to the Fedwire data.

⁸ Note that we exclude transactions occurring within a particular banking group as we aim at analyzing loans between distinct banks.

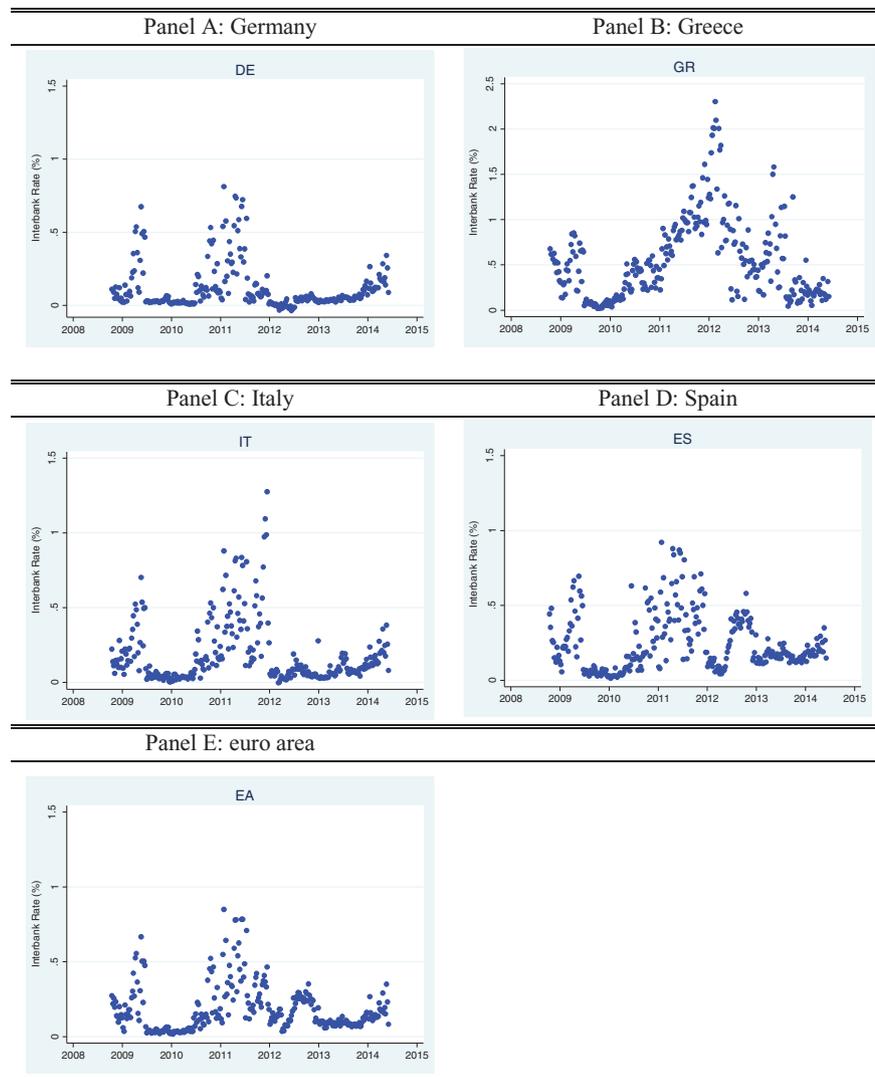


Fig. 1. Interbank rates (weekly).

Notes: Weekly average interest rate of interbank loans for borrowers in Germany (Panel A), Greece (Panel B), Italy (Panel C), Spain (Panel D) and the euro area (Panel E). The interbank rate is presented as a spread over the deposit facility rate, and it is weighted by total volume.

4. Identification and econometric strategy

The aim of our study is to examine the causal impact of changes in central bank excess liquidity provision (i.e., the provision in excess of what is necessary to satisfy reserve requirements) on the functioning of the (overnight unsecured) interbank market in the euro area. Establishing causality is challenging given the feedback between excess liquidity and interbank trading: does the interbank market react to the provision of liquidity by the Eurosystem, or do banks change their demand for liquidity from the Eurosystem in response to conditions in the interbank market? Moreover, we are interested in how stress during the sovereign debt crisis affects the relationship between excess liquidity and interbank market activity.

We examine interactions between excess liquidity and interbank trading using a structural VAR framework. To establish causality between excess liquidity and interbank activity, we exploit the timing of the Eurosystem's liquidity operations (see Fig. 4). Importantly, banks can demand liquidity from the Eurosystem only on certain days. The Eurosystem allows banks to borrow on Tuesdays when it conducts the Main Refinancing Operations (MRO). On Wednesday morning banks receive the

amount borrowed. As the next MRO occurs only on the next Tuesday, the amount of excess liquidity is fixed from Wednesday until the next Tuesday. Hence, the excess liquidity established in an MRO on Tuesday cannot respond to interbank trading on subsequent days (Wednesday to Tuesday) until the allotment of the next MRO on Wednesday morning. Yet, interbank trading from Wednesday to next Tuesday can react to the amount of excess liquidity borrowed in the MRO on Tuesday (see Fig. 4).

To exploit the timing of the Eurosystem's liquidity operations, we conduct our analysis at the weekly frequency. We calculate the volume-weighted average of interbank rates and total volume of interbank loans over a week from Wednesday until the next Tuesday.⁹ The excess liquidity for the same week is the excess liquidity on Wednesday (when MROs are settled).¹⁰ Hence, interbank rates and volumes in week t can respond to excess liquidity in week t ,

⁹ In addition, we adjust for holiday periods (such as April or December), taking into consideration TARGET2 closing days. For this, we follow the official ECB calendar of open market operations.

¹⁰ See Appendix for details on the construction of the excess liquidity series.

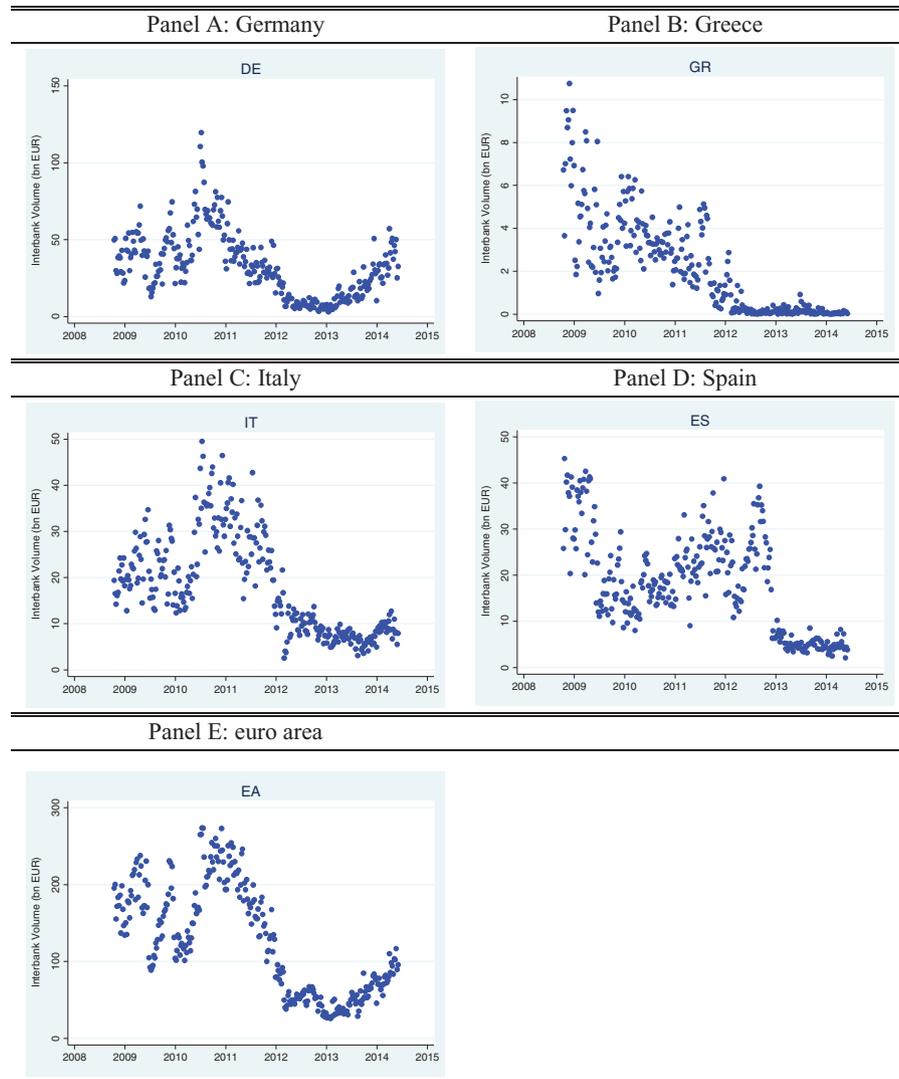


Fig. 2. Interbank volumes (weekly).

Notes: Weekly volume of interbank loans for borrowers in Germany (Panel A), Greece (Panel B), Italy (Panel C), Spain (Panel D) and the euro area (Panel E).

but excess liquidity cannot respond to interbank rates and volumes in the same week.¹¹

We allow for dynamic feedback effects. Excess liquidity, interbank rates and volumes in week t all can respond to the realization of all three variables in the previous week $t-1$. So excess liquidity can respond to previous interbank market activity and interbank activity can respond to previous excess liquidity.¹²

Consider then the following structural VAR where the three endogenous variables (excess liquidity, quantity and price) are collected in the vector $Z_t = [EL_t, Q_t, P_t]'$:

$$A \cdot Z_t = \Phi \cdot Z_{t-1} + D \cdot CDS_t + H_1 \cdot F_{3yr1} + H_2 \cdot F_{3yr2} + \varepsilon_t \quad (1)$$

where A and Φ are 3×3 full-rank matrices and $E[\varepsilon_t \varepsilon_t'] = I$. To control for bank risk, we include the current realization of aver-

¹¹ One concern with this identification assumption is that banks' borrowing from the Eurosystem on a Tuesday is affected by banks' *expectations* about trading conditions in the interbank market later in the week. This would imply a contemporaneous link between excess liquidity and interbank variables. In Section 7.1, we check whether such a link exists by testing whether market forecasts of the liquidity take-up in Eurosystem liquidity operations are correlated with our structural VAR residuals. We find no statistically significant relation between the two (see Section 7.1 for details).

¹² Our VARs include 1 lag, as chosen by the Schwarz criterion.

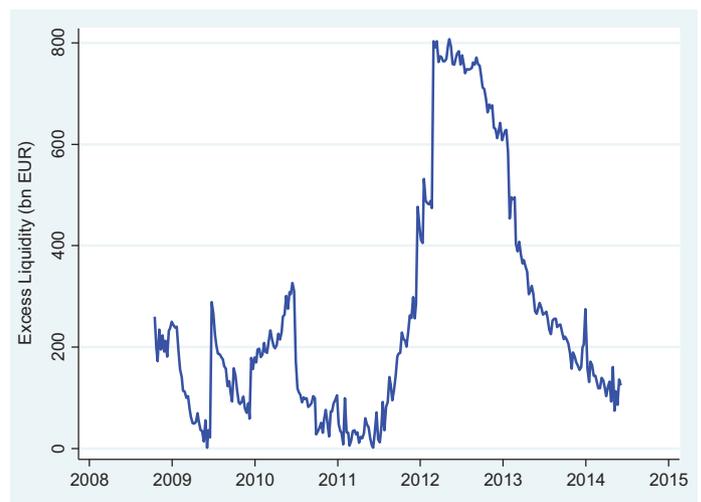


Fig. 3. Excess liquidity in the euro area.

Notes: Excess liquidity in the euro area (in EUR billion) (weekly). See Appendix for adjustments to the series needed due to non-regular operation market operations.

Table 1

Description of variables and data sources.

Excess liquidity (bn EUR): deposits at the deposit facility net of the recourse to the marginal lending facility, plus current account holdings in excess of those contributing to the minimum reserve requirements. Source: European Central Bank. Frequency: weekly (excess liquidity level on Wednesday of each week). See [Appendix](#) for more details.

Interbank volume (bn EUR): total weekly volume of unsecured overnight borrowing. Source: TARGET2 data. Frequency: weekly from Wednesday to Tuesday. See [Appendix](#) for more details.

Interbank rate spread (pct): average borrowing overnight interest rate (weighted by total volume) and as a spread over the deposit facility rate. Source: TARGET2 data. Frequency: weekly from Wednesday to Tuesday. See [Appendix](#) for more details.

Domestic vs. cross-border transactions: In the case of an individual country (Germany, Greece, Spain and Italy), we define domestic (cross-border) loans as those that occur between banks located in the same (different) country. In the case of the euro area, we first identify domestic and cross-border transactions within individual euro area countries and then aggregate them across all countries (summing up in case of volumes and volume-weighting in case of rates).

Bank CDS (basis points): country average CDS price (weighted by total volume). Source: Credit Market Analysis. Frequency: weekly from Wednesday to Tuesday. See [Appendix](#) for more details.

Forecast liquidity (bn): Median forecast of banks take-up in ECB liquidity operations; Source: Thomson Reuters. Frequency: weekly from Wednesday to Tuesday. See [Appendix](#) for more details.

1-year EDF (pct): expected default frequencies over one year (weighted by total assets). Source: KMV Moody's. Frequency: weekly from Wednesday to Tuesday.

Sovereign CDS (basis points): Senior Debt 5-year CDS. Source: Datastream. Frequency: weekly from Wednesday to Tuesday.

Table 2

Summary statistics: entire market.

Variable	Mean (standard deviation); sub-period 1	Mean (standard deviation); sub-period 2
Euro area		
Excess liquidity	123.42 (85.16)	397.07 (248.62)
Bank CDS	158.20 (41.54)	263.91 (115.34)
Interbank volume	182.27 (46.87)	70.84 (38.53)
Interbank rate spread	0.20 (0.21)	0.16 (0.09)
Germany		
Bank CDS	125.99 (23.69)	129.96 (52.82)
Interbank volume	46.72 (18.85)	19.31 (12.84)
Interbank rate spread	0.17 (0.20)	0.06 (0.06)
Greece		
Bank CDS	584.15 (417.49)	1477.11 (673.71)
Interbank volume	3.86 (1.92)	0.49 (0.94)
Interbank rate spread	0.40 (0.28)	0.69 (0.52)
Italy		
Bank CDS	140.04 (53.99)	340.72 (122.95)
Interbank volume	25.57 (8.57)	11.16 (7.20)
Interbank rate spread	0.21 (0.22)	0.15 (0.20)
Spain		
Bank CDS	222.98 (77.88)	323.21 (118.10)
Interbank volume	21.62 (8.98)	14.52 (10.98)
Interbank rate spread	0.26 (0.23)	0.23 (0.14)

Notes: Mean and standard deviation (in parenthesis) for all variables and countries, sample split according to time. Weekly data, sub-period 1 is from October 15, 2008 to July 19, 2011 (144 observations); sub-period 2 is from July 20, 2011 to June 10, 2014 (151 observations). The variables are: excess liquidity in the euro area (in EUR billion); country-specific banking sector senior 5-year credit default swap (Bank CDS; in basis points), interbank volume (in EUR billion), and interbank interest rate spread to the deposit facility (DF; in percent).

age bank CDS prices as an exogenous variable with coefficients collected in the vector D . The terms F_{3yr1} and F_{3yr2} are vector dummies that take the value one in the two weeks in which the two 3-year LTROs occur (on 22nd December 2011, week 167, and on 1st March 2012, week 177). H_1 and H_2 are vectors of coefficients associated with the dummies.

To obtain the dynamic responses to the structural shocks ε_t , we estimate the reduced-form VAR:

$$Z_t = B \cdot Z_{t-1} + E \cdot CDS_t + G_1 \cdot F_{3yr1} + G_2 \cdot F_{3yr2} + e_t, \quad (2)$$

where B denotes $A^{-1} \cdot \Phi$, E denotes $A^{-1} \cdot D$, G_1 denotes $A^{-1} \cdot H_1$, G_2 denotes $A^{-1} \cdot H_2$, and e_t denotes $A^{-1} \cdot \varepsilon_t$. We couch our results in the form of impulse-response functions (IRFs henceforth), estimated in the usual way. Bootstrapped 90% confidence intervals are based on 500 replications.

To identify the VAR system, we use a standard Cholesky decomposition of the estimate of the variance-covariance matrix. We order excess liquidity first, followed by quantities and then prices.¹³ Ordering excess liquidity first is in line with our identification argument that excess liquidity, because of the timing of Eurosystem liquidity operations, does not respond contemporaneously to interbank prices and quantities. This timing argument allows us to identify *only* the structural shock to excess liquidity. The ordering of quantities and prices is arbitrary. We are not interested in the structural shocks to interbank prices and quantities, which we can-

¹³ This ordering imposes three exclusion restrictions on the matrix A , making it lower-triangular.

Table 3
Summary statistics: domestic market.

Variable	Mean (standard deviation); sub-period 1	Mean (standard deviation); sub-period 2
Euro area		
Interbank volume	88.69 (21.11)	41.84 (16.92)
Interbank rate spread	0.23 (0.22)	0.20 (0.12)
Germany		
Interbank volume	24.87 (9.55)	9.55 (6.13)
Interbank rate spread	0.17 (0.20)	0.06 (0.06)
Greece		
Interbank volume	3.39 (1.45)	0.48 (0.94)
Interbank rate spread	0.40 (0.29)	0.72 (0.53)
Italy		
Interbank volume	13.79 (3.38)	8.39 (3.82)
Interbank rate spread	0.25 (0.24)	0.18 (0.27)
Spain		
Interbank volume	17.37 (8.80)	9.77 (7.21)
Interbank rate spread	0.27 (0.24)	0.27 (0.20)

Notes: Mean and standard deviation (in parenthesis) for all variables and countries, sample split according to time. Weekly data, sub-period 1 is from October 15, 2008 to July 19, 2011 (144 observations); sub-period 2 is from July 20, 2011 to June 10, 2014 (151 observations). The variables are interbank volume (in EUR billion) and interbank interest rate spread to the deposit facility (DF; in percent). In the case of the euro area, we first identify domestic transactions within individual euro area countries and then aggregate them across countries (summing up in case of volumes and volume-weighting in case of rates).

Table 4
Summary statistics: cross-border market.

Variable	Mean (standard deviation); sub-period 1	Mean (standard deviation); sub-period 2
Euro area		
Interbank volume	93.59 (33.91)	29.00 (23.91)
Interbank rate spread	0.18 (0.20)	0.09 (0.07)
Germany		
Interbank volume	21.85 (11.29)	9.76 (9.05)
Interbank rate spread	0.16 (0.20)	0.07 (0.06)
Greece		
Interbank volume	0.46 (0.71)	0.01 (0.01)
Interbank rate spread	0.25 (0.23)	0.23 (0.37)
Italy		
Interbank volume	11.78 (8.47)	2.77 (3.90)
Interbank rate spread	0.17 (0.21)	0.09 (0.09)
Spain		
Interbank volume	4.25 (2.77)	4.74 (5.32)
Interbank rate spread	0.19 (0.23)	0.15 (0.13)

Notes: Mean and standard deviation (in parenthesis) for all variables and countries, sample split according to time. Weekly data, sub-period 1 is from October 15, 2008 to July 19, 2011 (144 observations); sub-period 2 is from July 20, 2011 to June 10, 2014 (151 observations). The variables are interbank volume (in EUR billion) and interbank interest rate spread to the deposit facility (DF; in percent). In the case of the euro area, we first identify cross-border transactions within individual euro area countries and then aggregate them across countries (summing up in case of volumes and volume-weighting in the case of rates).

not identify. Accordingly, we never examine impulse responses to price or quantity shocks.¹⁴

We estimate the VAR for the euro area as a whole and at the country level for Germany, Italy, Spain and Greece. This approach is motivated by a considerable heterogeneity in the relationship between excess liquidity and interbank market activity, apparent from Fig. 5. The Figure shows the relationship between excess liquidity and interest rates on interbank loans (interest rate is pre-

sented as the spread relative to the rate offered on the ECB's deposit facility). For Germany (Panel A), a euro area country arguably least subject to sovereign stress, there is a clear negative relationship between excess liquidity and rates: As excess liquidity increases, interbank rates in Germany fall. By contrast, for Greece (Panel B), a country most subject to sovereign stress, there is no clear relationship between excess liquidity and interest rates. For any level of excess liquidity, transactions take place at many different rates. At times, the spread relative to the deposit rate is above two percent, which is twice as high as the spread prevailing in the other countries in our sample. Fig. 5, Panels C and D show the relationship between excess liquidity and interest rates in Italy and Spain, two large countries whose fiscal problems played an

¹⁴ Ordering excess liquidity first in the Cholesky decomposition means that the structural shock to excess liquidity is equal to the innovation in the first row of (2), which describes the dynamics of excess liquidity. For this reason, the ordering of prices and quantities in the decomposition does not matter.

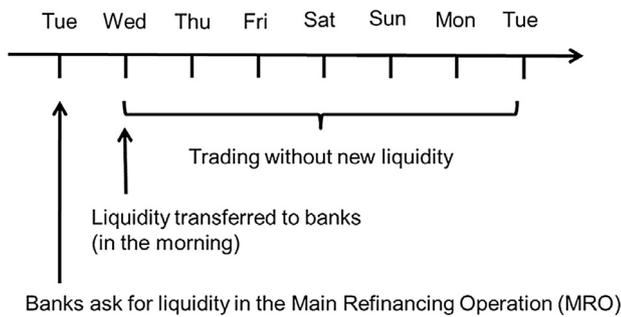


Fig. 4. The timing of the Eurosystem's Main Refinancing Operations (MRO). Notes: Simplified and illustrative timing of Eurosystem's Main Refinancing Operations (MRO). See [Appendix](#) for adjustments to the series due to non-regular operation market operations.

important part in the sovereign debt crisis. In Italy (Panel C), the relationship between excess liquidity and rates looks mostly like the one in Germany except for the observations that occur at the height of the sovereign debt crisis between mid-2011 until mid-2012. In Spain (Panel D), there is a negative relationship between

excess liquidity and rates, but it is weak. For any level of excess liquidity, many different interest rates are possible.

As for the relationship between excess liquidity and the volume of interbank loans (not shown), there is a negative relationship in all countries, but some differences between countries remain. In Germany, for example, the relationship is mostly linear up to EUR 450 billion of excess liquidity. Beyond EUR 450 billion of excess liquidity, trading volumes are very small and are broadly unchanged if excess liquidity increases further. In Greece, Italy and Spain, the negative relationship is weaker than in Germany and, in the case of Spain, there is trading even at very high excess liquidity levels.

Since the heterogeneity is present not only across countries but also within countries over time, we estimate each of the country-VARs separately for the period before and after 19th July 2011. Mid-July 2011 is the moment just before the sovereign debt crisis erupts in full force. As of this moment, Italy and Spain in particular come under severe stress and yields on Italian and Spanish government bonds reach new heights in late 2011. As of mid-July 2011, excess liquidity increases dramatically reaching record level with the two 3-year LTROs in December 2011 and March 2012 ([Fig. 3](#)). Owing to the exceptional nature of these two operations at the peak of the sovereign debt crisis, our baseline econometric model includes two dummies to take them into account. We come back

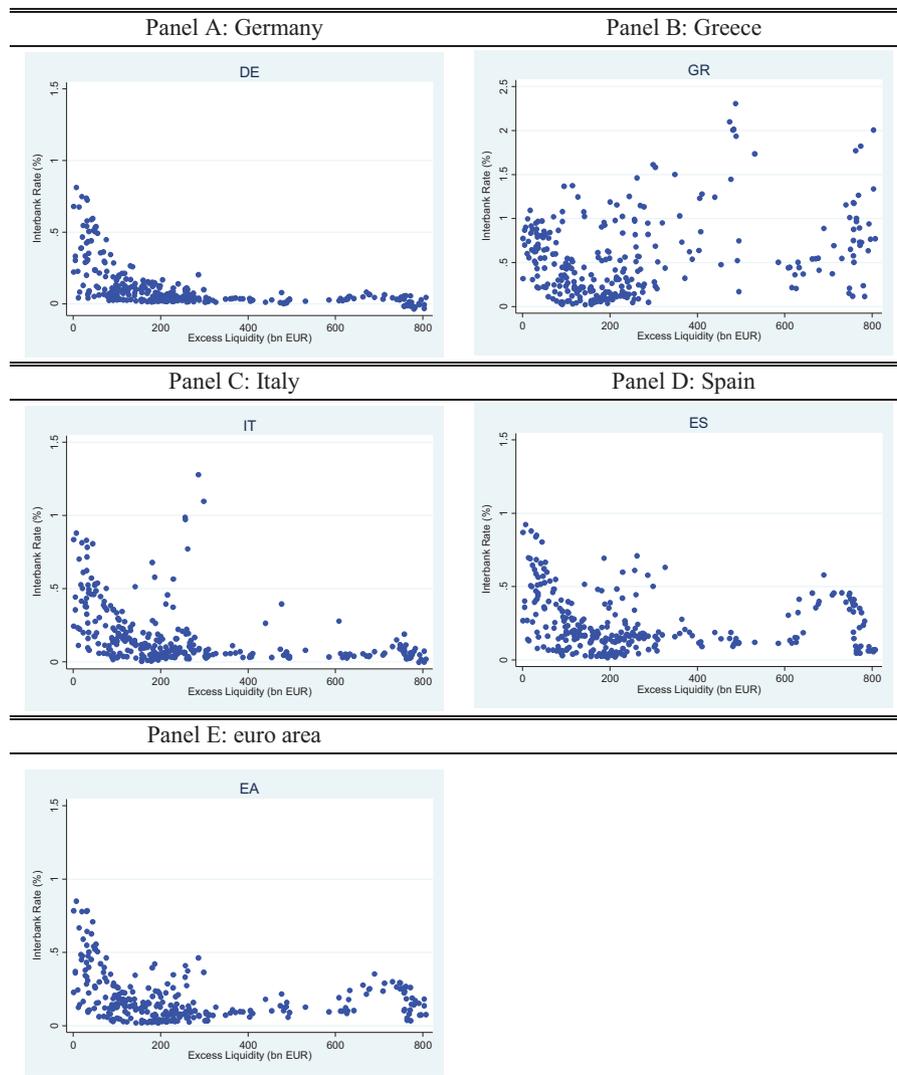


Fig. 5. Relationship between excess liquidity and interest rates across euro area.

Notes: Relationship between weekly excess liquidity and the weekly average interest rate of interbank loans for borrowers in Germany (Panel A), Greece (Panel B), Italy (Panel C), Spain (Panel D) and euro area (Panel E). The interbank rate is presented as a spread over the deposit facility rate, and it is weighted by total volume.

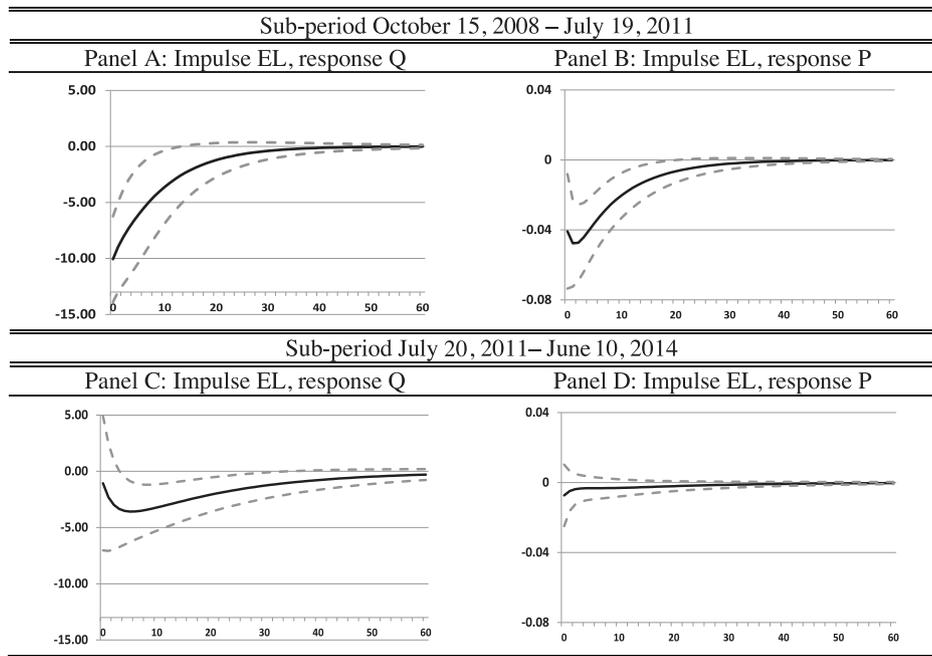


Fig. 6. Impact of the excess liquidity shock in the euro area.

Notes: Estimated structural impulse-response functions (black lines) and 90% bootstrapped confidence intervals (grey dashed lines) for the VAR with three endogenous variables (excess liquidity (EL, in EUR billion), interbank volume (Q, in EUR billion), and interbank interest rate spread to the deposit facility (P, in percent)) with 1 lag (selected by the Schwarz criterion), based on 500 replications. Bank credit default swaps weighted by interbank volume (CDS) enters as an exogenous variable. Weekly data, sample from October 15, 2008 to June 10, 2014. The top panel presents results for the sub-period till mid-2011; the bottom panel presents results for the sub-period till mid-2011.

to the issue of the two 3-year LTRO in Section 7.1 where we use market forecasts of Eurosystem liquidity provision to assess the robustness of our empirical specification.¹⁵

In sum, we estimate a set of 10 VARs across time and countries which allows us to differentiate between stressed and non-stressed interbank markets. Note that we control for the *level* of bank risk within a country (or within the euro area) because higher risk can affect interbank market activity and, at the same time, lead to higher central bank liquidity provision. The set of VARs then captures the *differential* impact of risk (stress) on the relationship between excess liquidity and interbank market activity.

In line with standard narratives of the sovereign debt crisis in Europe (Acharya et al., 2015) we label the German interbank market as non-stressed, both before and after mid-July 2011, the Italian and Spanish market as stressed after mid-July 2011, and the Greek market as stressed both before and after mid-July 2011.

5. Results

In this section, we present the results of our VAR analysis. Specifically, we discuss the impulse responses of the volume and interest rate of (overnight unsecured) interbank loans to a positive one standard deviation shock to excess liquidity. We first examine the impact on interbank volumes and rates for the euro area as a whole. We then analyze volumes and rates for borrowers located in Germany, Greece, Italy and Spain, respectively. In each case, we show impulse responses for the periods before and after mid-2011 to take into account the intensification of the sovereign debt crisis.

¹⁵ We also conducted our analysis with an alternative sample split according to the excess liquidity levels (above / below EUR 200 billion). As there are large overlaps between the sample split according to time and according to the excess liquidity levels, the results for the two sample splits are very similar. Detailed results for the sample split according to the excess liquidity levels can be found in the working paper version of the article (see Garcia-de-Andoain et al., 2016).

5.1. The euro area interbank market

In the period until mid-2011 (Fig. 6, Panels A and B), the size of a one standard deviation shock to excess liquidity is EUR 35.83 billion. A positive excess liquidity shock of that size decreases the volume of interbank loans by 10.06 billion (this is also the maximum impact). The negative impact of the excess liquidity shock is significant for eleven weeks. More excess liquidity also leads to a statistically significant decrease of the interest rate for seventeen weeks. The maximum impact is minus 0.05 percentage points, which occurs after one week.

In the period after mid-2011 (Fig. 6, Panels C and D), the size of a one standard deviation shock to excess liquidity is EUR 28.74 billion. Such a positive excess liquidity shock decreases the interbank volume significantly after week three until week thirty-nine. The negative impact reaches a maximum of minus 3.58 billion in week five. Higher excess liquidity also lowers the interbank interest rate but the impact is only borderline statistically significant.

In sum, when there is more central bank liquidity, there is less trading in the interbank market and loans have lower interest rates. The effects are smaller after mid-2011, which is not surprising given that interbank trading declined more than 2.5-fold compared to the previous sub-period (see Table 2) and given the high degree of heterogeneity across countries during the sovereign debt crisis (see Fig. 5).

5.2. Interbank market in a non-stressed country: Germany

In the sub-period until mid-2011 (Fig. 7, Panels A and B), a positive one standard deviation shock to excess liquidity (EUR 35.83 billion) decreases the interbank volume on impact by 4.38 billion. The effect is significant for two weeks. Higher excess liquidity also significantly decreases the interbank rate for fourteen weeks, with the maximum impact reaching 0.05 percentage points after one week.

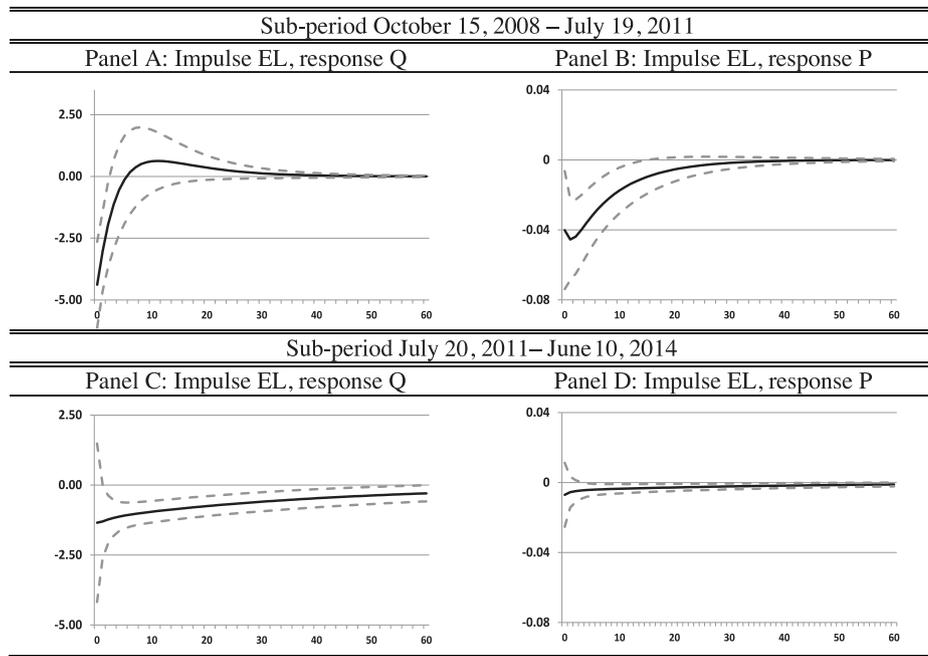


Fig. 7. Impact of the excess liquidity shock in Germany.

Notes: Estimated structural impulse-response functions (black lines) and 90% bootstrapped confidence intervals (grey dashed lines) for the VAR with three endogenous variables (excess liquidity (EL, in EUR billion), interbank volume (Q, in EUR billion), and interbank interest rate spread to the deposit facility (P, in percent)) with 1 lag (selected by the Schwarz criterion), based on 500 replications. Bank credit default swaps weighted by interbank volume (CDS) enters as an exogenous variable. Weekly data, sample from October 15, 2008 to June 10, 2014. The top panel presents results for the sub-period till mid-2011; the bottom panel presents results for the sub-period till mid-2011.

In the sub-period after mid-2011 (Fig. 7, Panels C and D), a one standard deviation shock to excess liquidity (EUR 28.74 billion) has a persistent, negative impact on the interbank volumes. The impact reaches a maximum of minus 1.23 billion in week two, and is significant from week two until week sixty. Higher excess liquidity lowers the interbank rate but only minimally (by a maximum of 0.004 percentage points on impact). The decrease in the interest rate is persistent and statistically significant from week four until week sixty.

The impact of an increase in central bank liquidity provision on the functioning of the German interbank market is similar to the interbank market of the entire euro area (as a large fraction of interbank activity in the euro area occurs in Germany). It leads to a lower volume of interbank loans and lower interest rates.

5.3. Interbank market in a stressed country: Greece

In the sub-period until mid-2011 (Fig. 8, Panels A and B), a one standard deviation shock to excess liquidity (EUR 35.83 billion) lowers interbank volume by 0.17 billion on impact, but the effect is not statistically significant. Higher excess liquidity decreases the interbank rate for six weeks and the maximum impact of minus 0.04 percentage points occurs immediately.

In the sub-period after mid-2011 (Fig. 8, Panels C and D), the excess liquidity shock (EUR 28.74 billion) leads to a very small but persistent reduction in the interbank volume (a maximum of 0.04 EUR billion, statistically significant from week five until week forty-three). The shock has no statistically significant effect on rates. We should note, however, that there was very little trading in the Greek interbank market in this sub-period (see Table 2). This may explain the lack of any sizable and significant response.

5.4. Interbank market in a temporarily stressed country: Italy

In the sub-period till mid-2011 (Fig. 9, Panels A and B), a one standard deviation shock to excess liquidity (EUR 35.83 billion) im-

mediately lowers interbank volume by 1.62 billion. The reduction is statistically significant for one week. Higher excess liquidity decreases the interbank interest rate on impact by 0.04 percentage points and the decrease remains statistically significant for eleven weeks. These impulse responses are similar to those in Germany, as observed already in the raw data (see Fig. 5). More central bank liquidity leads to a lower volume of interbank loans and to lower interest rates in Italy.

In the sub-period after mid-2011 (Fig. 9, Panels C and D), a one standard deviation shock to excess liquidity (EUR 28.74 billion) has no statistically significant impact on the volume of interbank loans (the point estimates also are virtually zero). A positive excess liquidity shock decreases the interbank interest rates in a statistically significant way as of week three until week forty-six. The maximum decrease is 0.02 percentage points, which occurs in week ten. For the period after mid-2011, the impulse responses in Italy are different from those in Germany. In fact, a decrease in interest rates without a corresponding change in volume is similar to the pattern in Greece (before mid-2011). That is, the VAR analysis confirms our initial assessment of stress in the Italian interbank during the intensification of the sovereign debt crisis since mid-2011.

5.5. The interbank market in Spain

In the sub-period till mid-2011 (Fig. 10, Panels A and B), a one standard deviation shock to excess liquidity (EUR 35.83 billion) has hardly any impact on interbank volume (minus 0.71 billion on impact, not statistically significant). But the excess liquidity shock decreases the interbank rate in a statistically significant way for twelve weeks. The maximum decrease is 0.04 percentage points and occurs in week one. The pattern (no impact on volume and a reduction of interest rates) is similar to the one in Greece during the same period, and it also is similar to the one in Italy after mid-2011. This suggests that the Spanish interbank market is stressed already during the financial crisis stage, and before the intensification of the sovereign debt crisis.

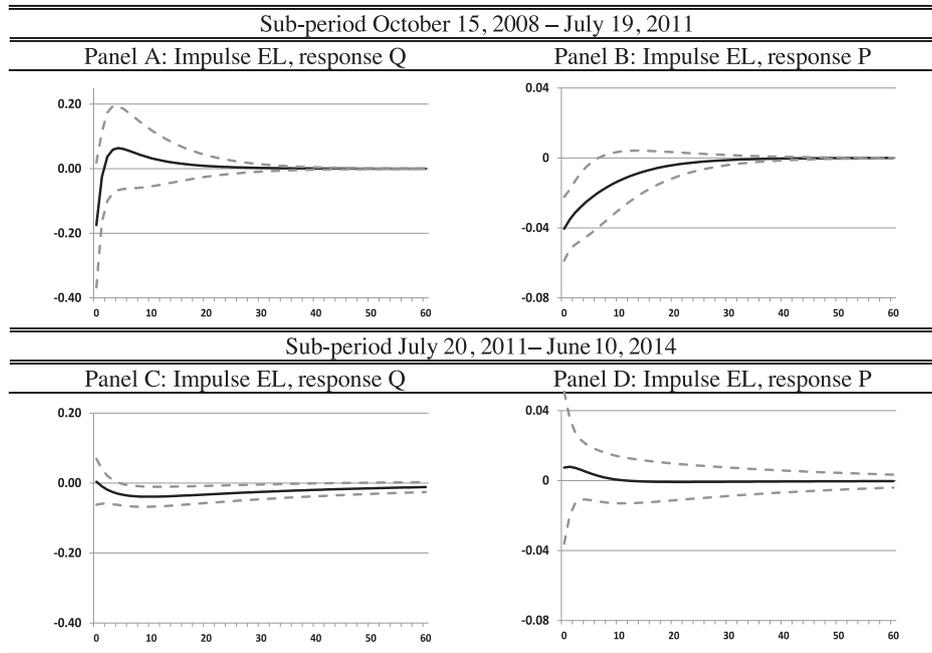


Fig. 8. Impact of the excess liquidity shock in Greece.

Notes: Estimated structural impulse-response functions (black lines) and 90% bootstrapped confidence intervals (grey dashed lines) for the VAR with three endogenous variables (excess liquidity (EL, in EUR billion), interbank volume (Q, in EUR billion), and interbank interest rate spread to the deposit facility (P, in percent)) with 1 lag (selected by the Schwarz criterion), based on 500 replications. Bank credit default swaps weighted by interbank volume (CDS) enters as an exogenous variable. Weekly data, sample from October 15, 2008 to June 10, 2014. The top panel presents results for the sub-period till mid-2011; the bottom panel presents results for the sub-period till mid-2011.

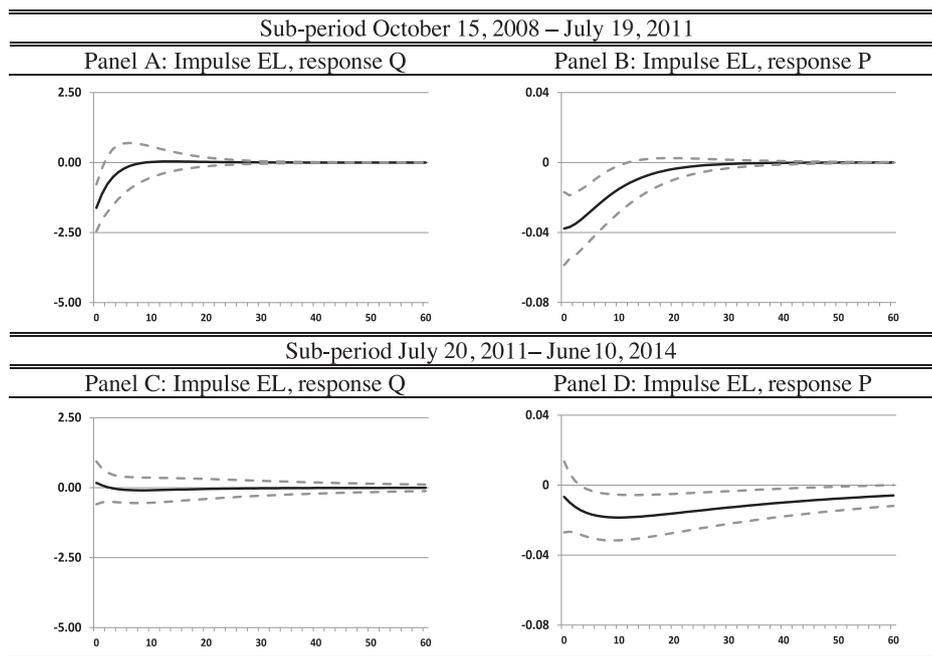


Fig. 9. Impact of the excess liquidity shock in Italy.

Notes: Estimated structural impulse-response functions (black lines) and 90% bootstrapped confidence intervals (grey dashed lines) for the VAR with three endogenous variables (excess liquidity (EL, in EUR billion), interbank volume (Q, in EUR billion), and interbank interest rate spread to the deposit facility (P, in percent)) with 1 lag (selected by the Schwarz criterion), based on 500 replications. Bank credit default swaps weighted by interbank volume (CDS) enters as an exogenous variable. Weekly data, sample from October 15, 2008 to June 10, 2014. The top panel presents results for the sub-period till mid-2011; the bottom panel presents results for the sub-period till mid-2011.

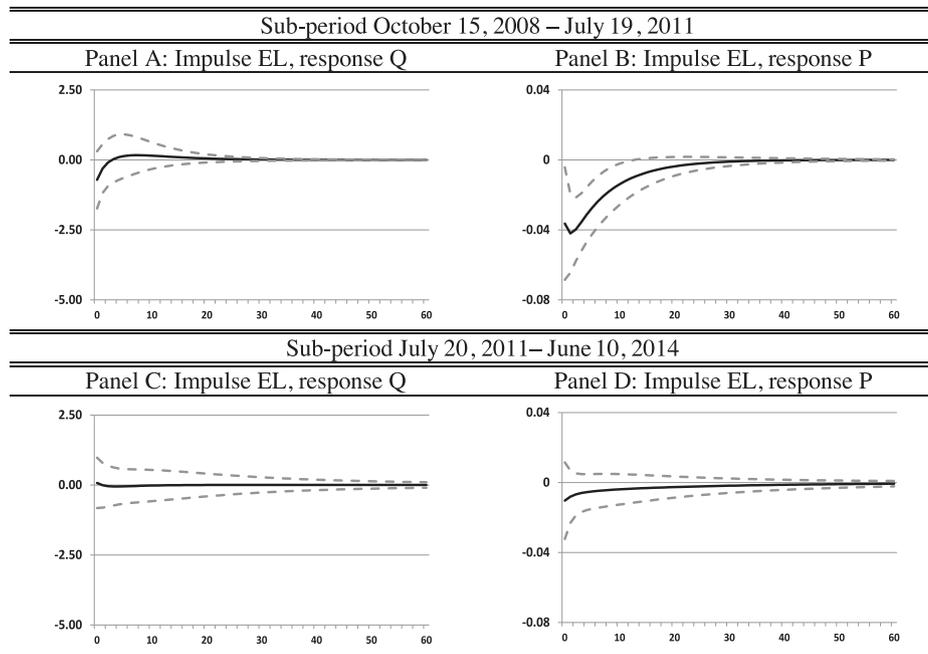


Fig. 10. Impact of the excess liquidity shock in Spain.

Notes: Estimated structural impulse-response functions (black lines) and 90% bootstrapped confidence intervals (grey dashed lines) for the VAR with three endogenous variables (excess liquidity (EL, in EUR billion), interbank volume (Q, in EUR billion), and interbank interest rate spread to the deposit facility (P, in percent)) with 1 lag (selected by the Schwarz criterion), based on 500 replications. Bank credit default swaps weighted by interbank volume (CDS) enters as an exogenous variable. Weekly data, sample from October 15, 2008 to June 10, 2014. The top panel presents results for the sub-period till mid-2011; the bottom panel presents results for the sub-period till mid-2011.

In the sub-period after mid-2011 (Fig. 10, Panels C and D), a one standard deviation shock to excess liquidity (EUR 28.74 billion) has no statistically significant effect on either volume or interest rates (in both cases, the point estimates are virtually zero). This is again similar to the impulse responses in Greece in this sub-period and may be a sign of overall reduced interbank activity after mid-2011.

6. Discussion

In this section we relate our results to a simple supply and demand framework to offer an economic interpretation of the impulse-responses of interest rates and volumes in the interbank market to an unexpected excess liquidity shock. Interest rates and quantities traded in the unsecured overnight interbank market are the result of the interplay between banks' demand for liquidity and banks' supply of liquidity.

Banks demand (borrow) liquidity from other banks to satisfy reserve requirements, to make payments, or to store value. Banks supply (lend) liquidity to other banks if they have more liquidity than they currently need. *Ceteris paribus*, banks demand less at higher interest rates and supply less at lower interest rates.¹⁶ Changes in central bank liquidity provision shift demand and supply in the interbank market and hence change interbank prices (interest rate) and quantities (volume).

Two statistically significant patterns emerge from our VAR estimations. First, a positive excess liquidity shock leads to less interbank volume and lower interest rates. This is the case in the euro area, in Germany, and in Italy, especially before mid-2011. If we are to interpret this result through the lens of a simple supply and demand framework, only a shift of the demand curve to the

left (with the supply curve being relatively constant) produces less volume and lower interest rates. Intuitively, when the central bank provides more liquidity to the market, banks demand less liquidity from other banks because they receive liquidity from the central bank.

Second, a positive excess liquidity shock lowers interest rates but leaves the interbank volume unchanged. This is the case in Greece (before mid-2011), Italy (after mid-2011) and in Spain (before mid-2011). In a simple supply and demand framework, only a shift of the demand curve to the left together with a shift of the supply curve to the right can produce a reduction in rates while keeping volumes constant. In this case, banks with a liquidity shortage demand less from the market, while banks with a liquidity surplus now supply more to the market.

We therefore have two results for the impact of the Eurosystem's lending-of-last-resort on the functioning of the interbank market. First, the ample provision of liquidity by the central bank generally replaces banks' demand for liquidity in the market. Second, the ample provision of liquidity by the central bank expands the supply of liquidity in stressed interbank markets. The LOLR stimulates the functioning of those markets that need it most.

7. Robustness

In this Section, we conduct three different robustness checks. First, we assess the fit of our model using survey-based forecasts of banks' recourse to the Eurosystem's open market operations. Second, we use alternative measures of risk (bank 1-year expected default frequency (EDF) and sovereign CDS). Third, we repeat our benchmark VARs while distinguishing between domestic and cross-border interbank transactions.¹⁷

¹⁶ In practice, trading in the interbank market occurs mostly over-the-counter, although there are some trading platforms (e.g., the Italian e-MID). To obtain the simplest possible interpretation of the impact of the provision of central bank liquidity on the functioning of the interbank market, we abstract from the precise micro mechanics of trade (for a search-theoretic model of the U.S. market for federal funds, see Afonso and Lagos, 2015).

¹⁷ For brevity, we omit the presentation of the impulse response functions. Those can be found in the working paper version of the article (see Garcia-de-Andoain et al., 2016).

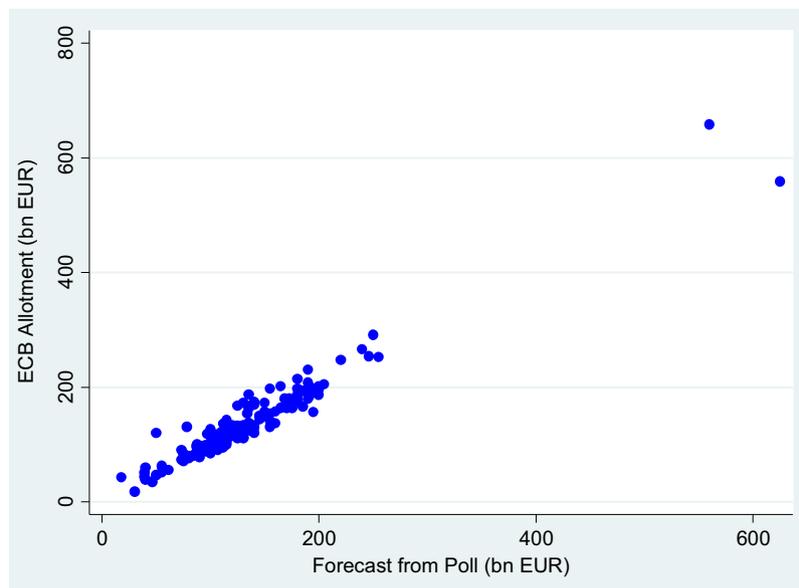


Fig. 11. Relationship between the ECB allotment and the liquidity forecast.

Notes: Relationship between Reuters' poll forecast for MROs and LTROs (in EUR billion; x-axis) and ECB allotment (in EUR billion; y-axis). The two points in the upper right corner correspond to the two 3-year LTROs for Dec. 22nd 2011 and Mar. 1st 2012 respectively. See [Appendix](#) for further details on the construction of the liquidity forecast variable.

7.1. Liquidity forecast

One concern with our VAR specification is that banks' borrowing from the Eurosystem on a Tuesday may be affected by banks' expectations about conditions in the interbank market later in the week. This would lead to a contemporaneous link between interbank activity and excess liquidity. Our identification scheme, however, depends on the absence of such a link.

We check for the existence of such expectation-based link using market forecasts of the recourse to Eurosystem operations. We use the Thomson Reuters poll on ECB liquidity take-up expectations that is conducted before the official allotment.¹⁸ Fig. 11 plots this forecast against actual borrowing. Most observations lie on the 45 degree line, which is an indication of the high accuracy of the forecast.

To check for the existence of a contemporaneous link based on expectations, we regress the structural residuals of our baseline VAR model against the median forecast in the Thomson Reuters poll. Our hypothesis is that there is no correlation between the residuals and the median forecast. That is, the market forecasts do not contain information about something that we miss in our baseline specification. If there was an expectation-based link, we should be able to reject the hypothesis of no correlation.

We find no statistically significant relation between the market forecast of borrowing from the Eurosystem and the residuals of our baseline VAR model.¹⁹

¹⁸ Because information in the Thomson Reuters poll does not exist or is incomplete before mid-2011, we could only perform this robustness check for the sub-period after mid-2011.

¹⁹ We should note that without dummies for the two three-year LTROs, there is a correlation between the forecast and the residuals. A VAR model without the dummies cannot predict the very large amount of borrowing in these two exceptional operations from the time-series of excess liquidity. Yet, the market forecast contained a lot of information about the borrowing in these two operations as both operations were communicated and explained to the market well in advance (the first communication took place following the Governing Council meeting on December 8, 2011).

7.2. Alternative measures of bank risk

In our main specification, we use banks' CDS to control for the level of stress in the interbank market. We then conduct our VAR analysis at the country level to allow for a differential impact of central bank liquidity provision on interbank activity depending on how stressed a country's interbank market is. We now check whether our results are robust when we use sovereign CDS or bank expected default frequencies (EDFs) as alternative controls.

When we use sovereign instead of bank CDS to control for the level of stress, the results remain essentially unchanged. The only change occurs in Italy after mid-2011 where both volumes and rates decline following an excess liquidity shock. The fact that our results are similar with sovereign and with bank CDS is not surprising as, in most cases, the correlation between bank CDS and sovereign CDS is above 0.9 in our sample. In the euro area, there is a close link between the stress of a country and the stress of that country's banks.

As an alternative to bank CDS, we also use banks' one-year expected default frequency (EDF) to control for the level of stress. Again, our results are largely unaffected.

7.3. Domestic versus cross-border interbank trade

In our benchmark VARs, the interbank variables are computed based on the geographical location of borrowing banks, aggregated to the country-level. We do not distinguish whether the lending bank comes from the same country, or from another euro area country. Given the capital flow reversal which took place during the sovereign debt crisis in the euro area, one may wonder whether the dynamics of overnight interbank trading was different for domestic and cross-border transactions and whether central bank liquidity provision affected these two types of transaction differently.

We therefore conduct our VAR analysis separately for domestic and cross-border interbank transactions. We examine whether the impact of excess liquidity shocks is similar. If it is, then our simple interpretation of the impact of the LOLR on total interbank activity

is robust and does not need to be expanded with a cross-border dimension.

Our results are broadly similar to our benchmark, which contains both domestic and cross-border loans. Only in the case of Italy in the period until mid-2011 do we see a slight difference. A one standard deviation shock to excess liquidity leads to a larger reduction in the volume for cross-border transactions compared to domestic transactions.

8. Conclusion

The task of a Lender of Last Resort is to provide liquidity at times when no private agent is willing to do so. According to Bagehot's famous adage, the LOLR should lend freely, against good collateral and at above normal rates. In this paper, we argue how the operational framework of the Eurosystem, even though it contains no explicit reference to the LOLR function, has proven flexible enough to deal with major systemic liquidity crises, while complying at the same time with the basic tenets of Bagehot rule.

Using a novel and comprehensive data set on euro area overnight unsecured interbank transactions between 2008 and 2014, the analysis of this paper sheds light on how central bank liquidity affects the functioning of the interbank markets across euro area countries. We find two main effects. In non-stressed interbank markets, increases in central bank liquidity reduce both the volume of transactions and interest rates in the interbank market. This is consistent with a lower demand for liquidity in the interbank market. In stressed interbank markets, increases in central bank liquidity reduce interest rates but leave the volume unchanged. This indicates both a lower demand for liquidity and a higher supply of liquidity in the market place.

Overall, LOLR in the euro area has a heterogeneous effect, generally substituting the private demand for liquidity but, importantly, expanding the private supply of liquidity in stressed interbank markets.

Appendix. Details on construction of variables

We use the official ECB calendar of open market operations to transform our dataset from daily to weekly frequency. We first identify holidays in the calendar that lead to uneven number of trading days for each week (holidays mainly occur in April and December). We then construct our MRO periods that span from the settlement of the MRO until the allotment of the next one (included). Example: MROs settle normally on Wednesdays so in general our MRO period includes the observations on Wednesday, Thursday, Friday, Monday and Tuesday. We use an id for each week running from 1 to 295. Week 1 starts Oct. 15 2008 and week 295 starts Jun. 4 2014.

Below we list in detail the changes we perform to our raw data variables before transforming the dataset from daily to weekly frequency:

Excess liquidity

For excess liquidity, we treat the first observation in the week (normally on Wednesday – except for special cases) as representative for the entire week or MRO period after making the following adjustments:

We replace the negative excess liquidity observation on Jun. 8 2011 with the minimum non-negative excess liquidity over the entire sample (1.302 bn).

We drop the excess liquidity observations for the days of the 1 and 3-year LTROs allotments (four 1-year LTROs and two 3-year LTROs). These operations were on Jun. 24 2009, Sep. 30 2009, Dec. 16 2009, Oct. 26 2011, Dec. 21 2011 and Feb. 29 2012. In essence, for these MRO periods (or weeks) we do not take the excess liquidity resulting from the MRO settlement as we normally do, but

the one resulting from the settlement of the 1 and 3-year LTROs one day after. We do so in order to accurately reflect the week's excess liquidity.

We explore in detail the cases related to repayments of LTROs (occur on Thursdays). We do not wish to use excess liquidity of the Wednesday (or day before repayment) but that of Thursday (day of repayment). Finally, we drop the Wednesday observations (day prior to repayment) and we treat the excess liquidity resulting from the repayment as the excess liquidity value for the week.

We also drop the observations at end of maintenance period's days that lead to negative daily excess liquidity level.

Forecast liquidity data from Thomson Reuters

We use for each week (MRO period) the total allotment and liquidity forecast (median) resulting from the settlement of MROs on Wednesdays, but with some adjustments:

First, we pool (sum) together the allotments and forecasts of MRO and 1-3 year LTROs. We disregard LTRO operations of less than 1 year (small in size and irregular). We only use the poll forecast in the second subsample (since mid-2011) due to missing observations prior. The sum of MRO and 1-3 year LTROs for the second sub-sample includes three operations: one 1-year LTRO (Oct. 26 2011) and two 3-year LTROs (Dec. 21 2011 and Feb. 29 2012).

We fill in the MRO forecast of May. 2 2012 which is missing in the Reuters poll and could not be traced historically. We replace it with the maturing operation of the week before. We do so as we find a strong overall correlation between the forecast and the outstanding maturity from the operation conducted the week before. We fill in a forecast of 46.4 bn for May 2 2012.

CDS

We merge all available CDS prices for all banks in TARGET2 to our interbank market transaction level data.

We finally calculate a country CDS price index as the average CDS price (weighted by total volume) for all banks in a given country during each week or MRO period.

Interbank volume

We adjust volumes considering the number of trading days in the week (trading = with overnight market activity). Our sample includes weeks with 3, 4, 5 and 6 days.

We adjust weekly volume as follows:

$$\begin{aligned} \text{volume} &= \text{volume} \times (5/3) \text{ if week had 3 trading days} \\ \text{volume} &= \text{volume} \times (5/4) \text{ if week had 4 trading days} \\ \text{volume} &= \text{volume} \times (5/6) \text{ if week had 6 trading days} \end{aligned}$$

Interbank rate

We compute the weighted average borrowing rate for each country with the weekly observations available for that week. If a week contains fewer observations due to a holiday, the average is only computed over the available data points for the week.

References

- Afonso, G., Kovner, A., Schoar, A., 2011. Stressed, not frozen: The Federal funds market in the financial crisis. *J. Financ.* 66, 1109–1139.
- Afonso, G., Lagos, R., 2015. Trade dynamics in the market for federal funds. *Econometrica* 83, 263–313.
- Angelini, P., Nobili, A., Picillo, C., 2011. The interbank market after August 2007: What has changed, and why? *J. Money, Credit Bank.* 43, 923–958.
- Acharya, V., Drechsler, I., Schnabl, P., 2014a. A pyrrhic victory? Bank bailouts and sovereign credit risk. *J. Financ.* 69 (9), 2689–2739.
- Acharya, V., Eisert, T., Eufinger, C. and Hirsch, C. (2015), "Real effects of the Sovereign debt crisis in Europe: evidence from syndicated loans", CEPR, Discussion Paper Series No. 10108.
- Acharya, V., Fleming, M.J., Hrungrung, W.B., and Sarkar, A. (2014b). "Dealer financial conditions and lender-of-last resort facilities," Staff Reports 673, Federal Reserve Bank of New York.
- Acharya, V., Merrouche, O., 2013. Precautionary hoarding of liquidity and the interbank markets: Evidence from the sub-prime crisis. *Rev. Financ.* 17, 107–160.
- Acharya, V., Tuckman, B., 2014. Unintended consequences of LOLR facilities: The case of illiquid leverage. *IMF Econ. Rev.* 62, 606–655.

- Acharya, V., Steffen, S., 2015. The greatest carry trade ever? Understanding Eurozone bank risks. *J. Financ. Econ.* 115 (2), 215–236.
- Arciero, L., Heijmans, R., Heuver, R., Massarenti, M., Picillo, C., Vacirca, F., 2016. How to measure the unsecured money market? The Eurosystem's implementation and validation using TARGET2 data. *International Journal of Central Banking* 12, 247–280.
- Armantier, O. and Copeland, A. (2015). "Assessing the quality of Furfine-based algorithms," Federal Reserve Bank of New York Economic Policy Review, October.
- Bagehot, W., 1873. *Lombard Street: A Description of the Money Market*. Henry S. King and Co, London.
- Board of Governors of the Federal Reserve System, "Monetary policy and policy tools" http://www.federalreserve.gov/monetarypolicy/bst_lendingdepository.htm (accessed 30.03.16).
- Bindseil, U., 2014. *Monetary Policy Operations and the Financial System*. Oxford University Press.
- Brunetti, C., Di Filippo, M., Harris, J.H., 2011. Effects of central bank intervention on the interbank market during the subprime crisis. *Rev. Financ. Stud.* 24, 2053–2083.
- Drechsler, I., Drechsel, T., Marques, D., Schnabl, P., 2014. Who borrows from the lender of last resort? *J. Financ.* forthcoming.
- Freixas, X., Holthausen, C., 2005. Interbank market integration under asymmetric information. *Rev. Financ. Stud.* 18, 459–490.
- Furfine, C., 1999. The microstructure of the federal funds market. *Financ. Mark., Inst., Instrum.* 8, 24–44.
- Furfine, C., 2001. Banks monitoring banks: Evidence from the overnight Federal funds market. *J. Bus.* 74, 33–58.
- Frutos, J.C., Garcia-de-Andoain, C., Heider, F., and Papsdorf, P. (2016). "Stressed interbank markets: Evidence from the European financial and sovereign debt crisis", ECB Working Paper, forthcoming.
- Gabrieli, S. and Georg, C.-P. (2014). "A network view on interbank liquidity", Working Paper, Banque de France.
- Garcia-de-Andoain, C., Heider, F., Hoerova, M. and Manganelli, S. (2016). "Lending-of-last-resort is as lending-of-last-resort does: Central bank liquidity provision and interbank market functioning in the euro area", ECB Working Paper No. 1886.
- Garcia-de-Andoain, C., Hoffmann, P., Manganelli, S., 2014. Fragmentation in the euro area interbank market. *Econ. Lett.* 125, 298–302.
- Heider, F., Hoerova, M., Holthausen, C., 2015. Liquidity hoarding and interbank market rates: The role of counterparty risk. *J. Financ. Econ.* 118, 336–354.
- Padoa-Schioppa, T. (1999). "EMU and banking supervision," lecture at the London School of Economics, February, <http://www.ecb.europa.eu/press/key/date/1999/html/sp990224.en.html> (accessed 30.03.16).