EUROPEAN CENTRAL BANK
EUROSYSTEM

Working Paper Series

Stefano Corradin, Suresh Sundaresan

LOLR policies, banks' borrowing capacities and funding structures

No 2738 / October 2022

Abstract

We investigate banks' benefits and costs of having access to LOLR. Integrating novel data sets we estimate the borrowing capacities of euro area banks at the ECB. Controlling for ratings, we find that banks with more fragile funding are likely to borrow more from the ECB during the great financial and euro area sovereign debt crises. We develop a dynamic model of a bank and calibrate it to our empirical estimates. A bank with access to LOLR has higher equity value and makes larger investments in new loans, but it is more leveraged, pays more dividends and issues less equity.

Keywords: LOLR, Collateral, Haircut, Borrowing Capacity, Liquidity
JEL Classification: G2, E5, E58

Non-technical summary

In the aftermath of the great financial crisis (GFC), the European Central Bank (ECB) extended significant liquidity assistance to banks, under an enlarging liquidity provision and collateral policy framework. As a result, banks increased their reliance on ECB liquidity, on average, during the period spanning the GFC, euro area sovereign debt crisis and the period covering the 3-year long-term refinancing operations (LTROs) of the ECB.

In this paper, we investigate bank's benefits and costs of having access to lender of last resort (LOLR). We first estimate the borrowing capacities of euro area banks (i.e. the amount of collateral that a bank could potentially pledge to the ECB in exchange of liquidity), their ex-ante credit and liquidity profiles (as measured by the Net Stable Funding Ratio (NSFR)), and their funding structures (composition of deposit and non-deposit debt). Our results provide evidence in support of the traditional role of ECB as a LOLR: after controlling for rating differences, banks with ex-ante more fragile funding relied more on ECB liquidity in the aftermath of GFC and euro area sovereign debt crises.

We then develop a dynamic model of a bank that finances its long-term assets by rolling over private deposits and debt and accesses LOLR liquidity, but faces frictions in equity issuance and asset liquidation. A key feature of our setting is that a bank dynamically changes the level of central bank debt in its liability structure, relative to its private debt and deposits level to manage its *illiquidity*. We calibrate our model to our empirical evidence to assess how a bank adjusts its decisions on investments, dividends and equity issuances in response to central bank liquidity policies.

Finally, we run a few policy experiments by varying bank's borrowing capacity and central bank penalty rates. Our model shows that bank's equity value and investment in new loans are larger when the bank has access to LOLR. However, the bank pays more dividends and issues less equity. Our results suggest that *tougher* collateral policies, namely higher haircuts and higher penalty rates, can mitigate these incentives that are stronger for banks that have a riskier capital structure and lower credit rating.

1 Introduction

In the aftermath of the great financial crisis (GFC), the European Central Bank (ECB) extended significant liquidity assistance to banks, under a changing liquidity provision and collateral policy framework.[1]

Using novel data sets and a dynamic calibrated model of banking, we document how banks differentially responded to ECB's provision of liquidity, and its collateral policies in choosing their privately optimal choice of lending, equity issuance, internal liquidity and dividends. We further identify the potential channels for such a differential response.

Banks increased their reliance on ECB liquidity, on average, during the period spanning the GFC, euro area Sovereign Debt Crisis and the period covering the long-term refinancing operations (LTROs) of the ECB. The collateral policies of central banks can change in a crisis period.[2] Using our data sets, we estimate the borrowing capacities of euro area banks, their ex-ante credit and liquidity profiles (as measured by the Net Stable Funding Ratios (NSFR)), and their funding structures (composition of deposit and non-deposit debt). Informed by this evidence, we show that, after controlling for rating differences, banks with ex-ante more fragile funding relied more on ECB liquidity in the aftermath of GFC and euro area sovereign debt crises.

Central to our theoretical investigation is a well specified counterfactual: How might banks have chosen their dividend policies, equity issuance decisions, liquidity buffers and loan portfolio decisions when they do *not* have access to central bank liquidity facilities, but are subject to closure based on minimum total capital requirements? Answering this question is critical to fully comprehend how banks tailor their responses to central bank liquidity provision, capital requirements, and its collateral policies. To this end, we develop a dynamic

---

[1] The liquidity provision changed via the full allotment and long term operations, and the collateral policy changed via eligibility and haircut policies.

[2] For example, ECB changed its collateral policies in response to the COVID-19 crisis, recently. See "Improving funding conditions for the real economy during the COVID-19 crisis: the ECB's collateral easing measures," (April 2020). See `https://www.ecb.europa.eu/press/blog/date/2020/html/ecb.blog200422~244d933f86.en.html`.

model of a bank which finances its long-term assets by rolling over private deposits and debt and accesses lender of last resort (LOLR) liquidity, but it faces frictions in equity issuance, asset liquidation and is subject to total capital requirements by resolution authorities. This is helpful in assessing the value of central bank liquidity to banks and how banks adjust their key decisions in response to central bank liquidity policies. We calibrate our model to our empirical evidence and examine the differential response of banks to central bank's liquidity provision along the empirical dimensions that we have estimated. We use the calibrated model to run a few policy experiments on LOLR policies by varying haircuts on eligible collateral and penalty rates to trace out the implications for banks' decisions on investments, dividends and equity issuances. The model also sheds light on how the extent of maturity transformation [rollover risk of deposits] by a bank can affect its decisions on dividends, and equity issuances.

1.1 Summary of key results

We use a proprietary dataset on the characteristics of asset and liabilities euro area banks from July 2007 to February 2015, together with the cost of bank debt and deposits and provision of new loans. Using bank level time series going back to August 2007 at monthly frequency, we construct estimates of *ex-ante* liquidity profiles of banks and find two key results. First, we find that banks that are ex-ante weakly capitalised before the crisis increase their ECB borrowings after the crisis, relative to strongly-capitalised banks. This confirms and complements the results obtained by Drechsler et al. (2016). Second, and more importantly, we find that banks with lower ex-ante liquidity profiles, as measured by the NSFR, relied more on ECB liquidity after controlling for the rating or risk-taking channel, following the crisis relative to banks with strong ex-ante liquidity profiles. This result provides evidence in support of the traditional role of ECB as a LOLR.

The borrowing capacity of banks depends on their asset composition and the margin policy of the central banks. Here we build on the work of Garleanu and Pedersen (2011), which shows the importance of margins on assets. Using our novel data sets on banks and ECB collateral policies, we estimate the borrowing capacity of euro area banks. This is also similar to the spirit of the contribution of Bai, Krishnamurthy, and Weymuller (2018) who quantify the asset liability mismatch.

The average borrowing capacity is around 26% when we include all the potential eligible assets (marketable securities and loans). There are two key empirical findings here. First, the borrowing capacity is positively correlated with the holdings of marketable securities (such as sovereign bonds) and negatively correlated with the implied ECB haircut showing that our measure is affected by changes in the ECB eligibility criteria and haircuts. In a related contribution Garleanu and Pedersen (2011) examines the key distinctions between the margin policy and the interest rate policy on their pricing implications for high margin and low margin assets. Woodford (2010) argues that the margin as a monetary policy tool may be more important in unusual states of the world, when the economy is in stress. Repullo (2005) shows that the penalty rates and margins may have very different implications on risk-taking by banks. Ashcraft, Garleanu, and Pedersen (2011) provide evidence from TALF and survey evidence that haircuts affect the required rates of returns. Corradin and Rodriguez-Moreno (2016) compare a matched sample of euro area sovereign bonds issued in both euro and US dollar and study the effect of ECB collateral and liquidity factors on the pricing variations. Second, our empirical results show a strong positive correlation between the borrowing capacity of banks and their take-up of ECB liquidity. In this context, Bocola (2016) uses a dynamic model to study the implications of sovereign risk on the cost of funding of banks and the effectiveness of financial intermediation. The latter effect also arises from banks' unwillingness to lend when exposed to sovereign risk. Reis (2013) argues that, given the resource constraints faced by central banks, it is not possible to resolve sovereign debt issues through policy interventions.[3] De Fiore, Hoerova, and Uhlig (2017) examine the role

---

[3] Drechsler et al. (2016) show that weakly-capitalized banks borrowed more from the central bank. Their dataset is drawn from the ECB and covers all the euro area banks. Fecht, Nyborg, and Rocholl (2011) show that weak banks tend to demand more liquidity from LOLR. The dataset used in this study is confined to German banks. Nyborg (2016) provides a detailed analysis of the collateral framework of ECB. He argues

of central bank collateral policy when the bank faces frictions in money markets. Their general equilibrium framework shows that when banks face decreasing access to unsecured funding, it can lead to moderate output contractions.

We provide further evidence by sorting banks along the pre-crisis rating and NSFR. This allows us to construct two groups of banks: 1) banks with low NSFR & low rating (**LL**) and 2) banks with high NSFR & high rating (**HH**). We document that these banks differ mainly on their funding structures (or liability structures) and much less on their assets. The literature has tended to mainly emphasise the risk-taking channel of the asset side while we emphasise the funding channel. We further show that these two groups of banks respond differentially to ECB's liquidity provision.

On the theoretical front, we build a model extending the insights of Bolton, Chen, and Wang (2011), Hugonnier and Morellec (2017), and Décamps et al. (2011). Our main contributions to this literature are two-fold: first, we model external debt such that the bank has to finance its long-term assets by rolling over risky debt and deposits. This modelling choice is motivated by our empirical finding that banks primarily differ in terms of their reliance on fragile funding sources. Second, banks in our setting have access to LOLR with associated collateral policies. Together, the rollover feature combined with having access to LOLR affect optimal policy decisions of banks in significant ways. In our setting, banks dynamically change the level of central bank debt in their liability structure, relative to their private debt and deposits level to manage their "illiquidity". Using our model, with the parameters informed by our empirical work we deliver the following new insights. In general, banks hold lower cash buffers (pay more dividends) and issue equity less often when they have access to central bank liquidity facilities relative to the counterfactual in which they have no access to LOLR. This result is to be viewed in the context of Stein (2013) who notes:

---

that the collateral framework of the central banks may have a distortionary effect: they may bias the private provision of liquidity. Bindseil et al. (2017) argue that the collateral framework has helped to "prevent large-scale liquidity-driven defaults of financial institutions in major advanced economies." It stresses that the broad collateral policy has helped to create and maintain an elastic supply of credit to the economy, and protected the economy from financial losses.

“.. from the start of 2007 through the third quarter of 2008, the largest U.S. financial firms - which, collectively, would go on to charge off $375 billion of loans over the next 12 quarters - paid out almost $125 billion in cash to their shareholders via common dividends and share repurchases, while raising only $41 billion in new common equity.”

While Stein (2013) was referring to the banks in the United States, we document a similar pattern in Eurozone banks as well: the banks of our sample paid euro 728 billion in dividends from October 2008 to January 2015 when the 3-year LTRO repayment was due. The overall liquidity drawn by the banks in our sample reached the maximum of euro 851 billion in March 2012 after the 3-year LTROs allotments (overall euro 1,150 billion for the entire euro area banking sector).

Figure 1 plots the average dividends payout over equity and the average liquidity drawn from the ECB over assets for all the banks in our sample for the period 2007 to 2015. The key takeaway is that while banks relied on ECB liquidity, they continued to pay dividends. In this context, our model shows that banks pay more dividends and issue less equity when they have the comfort of knowing that the central bank will lend to them in bad states, limited by only their borrowing capacity. In our policy experiments (see Section 5.3) we show that “tougher” collateral policies, namely a higher haircuts and higher penalty rates can mitigate these incentives. In addition, we find that LL group of banks encounter greater equity dilution in the counterfactual where they do not have access to central bank. This is due to their riskier capital structure and lower credit rating. With access to LOLR, however, they have almost the same equity dilution as the HH group of banks.

Banks with greater access to LOLR (i.e., with more eligible collateral or borrowing capacity) tend to invest more in new loan portfolios. This result resonates favourably with the primary objective of the LOLR in supporting the lending channel. This result is related to the work of Alves, Bonfim, and Soares (2021) who use the Portuguese Central Credit Register (CRC), which has monthly data on virtually all bank loans granted by Portuguese financial institutions. They combine this with the monthly information on banks’ liquidity, capital and balance sheet items, as well as on their holdings of Portuguese government bonds. In addition, they gather bank-level data on the recourse to monetary policy operations and standing facilities, the collateral pool and reserve requirements compliance. They show that the access to central bank liquidity allowed the banks to maintain their loan portfolio at a normal level despite the collapse of private credit markets. Carpinelli and Crosignani (2021) investigate how the extension of a pool of eligible collateral by the Italian government for the ECB 3−year LTROs restored bank credit supply after the previous unsecured wholesale funding dry-up. Van Bekkum, Gabarro, and Irani (2017) study the impact of the lower rating requirement for residential mortgage-backed securities announced in the context of the 3−year LTROs on bank lending in the Netherlands. They document that most affected banks by the policy increase loan supply and lower interest rates on new mortgage originations. Jasova, Mendicino, and Supera (2021) provide evidence that 3−year LTROs providing long-term funding reduced debt rollover risk of Portuguese banks has a positive effect and economically sizeable impact on bank lending to the real economy.

The roadmap of the paper is as follows. In Section 2, we describe the institutional background. Section 3 describes the data and contains our empirical results and stylised facts. Section 4 describes the dynamic model of a bank and the key economic ingredients of the modelling approach. In Section 5 we solve the model, calibrate the parameters of the model to data, and characterise the model implications. In this section, we also develop several policy experiments characterising how LOLR policies affect dividend policies, equity issuance decisions, default likelihood and equity values. Section 6 concludes.

2 Institutional background

We describe briefly in this section the key features of ECB credit operations that involve the exchange of collateral assets by banks against drawing liquidity from ECB, as this forms one of the key considerations for our model specification. A more detailed description can be found in Bindseil et al. (2017).

First, the ECB credit operations are effectively security lending transactions and their impact depends on the size and maturity of the operations. Prior to the GFC, the ECB had a cap on bank lending and distributed liquidity via auctions as part of its regular monetary policy implementation (Bindseil, Nyborg, and Strebulaev (2009), Cassola, Hortaçsu, and Kastl (2013)). In October 2008, the ECB decided to carry out its operations with *full allotment at fixed rate* to alleviate the liquidity stress faced by the euro area banks. This meant that banks can borrow an unlimited amount at the given interest rate as long as they provide sufficient collateral (i.e., the liquidity supply curve from ECB is completely elastic). The ECB mainly engages in two types of operations: main refinancing operations (MRO) and longer-term refinancing operations (LTRO).[4] MROs are regular liquidity-providing transactions with a weekly frequency and a maturity of one week. LTROs are liquidity-providing transactions offered every other week and usually have a maturity of one to three months. On two occasions during the time period that we consider, the ECB decided to provide liquidity with longer maturities, a $1-$year LTRO (July 2009) and two $3-$year LTROs (December 2011 and February 2012) to *"support bank lending and liquidity in the euro area"*.[5]

Second, the ECB provides liquidity to banks against collateral. The latter refers to marketable financial securities, such as bonds,[6] or non-marketable assets, such as loans (or credit claims).[7] The ECB applies a single collateral framework across all of its credit operations. This implies that the same pool of collateral can be used by bank counterparties

---

[4] In addition, the ECB also provides liquidity via the marginal liquidity facility (i.e. the equivalent of the discount window in the US), provides foreign-denominated funding via swaps with central banks (i.e. US dollar funding with US Federal Reserve), and offers liquidity to single banks outside the ECB monetary policy framework via emergency liquidity assistance (ELA). The provision of ELA lies with the national central bank (NCB) concerned. This means that any costs of, and the risks arising from, the provision of ELA are incurred by the relevant NCB.

[5] See `https://www.ecb.europa.eu/press/pr/date/2011/html/pr111208_1.en.html`.

[6] ECB-eligible marketable assets are generally euro-denominated investment-grade debt, such as sovereign debt, mortgage-backed bonds, covered bonds, bank bonds and corporate bonds.

[7] Three types of non-marketable assets are eligible as ECB collateral: fixed-term deposits from eligible counterparties, credit claims and non-marketable retail mortgage-backed debt instruments (RMBDs). Moreover, each national central bank can have specific national eligibility criteria for the temporary acceptance of additional credit claims (ACCs) as collateral in ECB credit operations.

when borrowing from various credit operations of ECB.

Third, because assets pose material interest rate and/or credit and/or liquidity risks, they can be used as collateral but not for their full market value. The ECB applies *haircuts* (i.e. the value of the security in excess of the liquidity exchanged) to have protection against such risks. The ECB haircuts are asset-specific and therefore it does not apply differentiated haircuts that are conditional on the creditworthiness of the individual bank counterparty.[8]

Finally, it is worth noting that if a counterparty defaults and the liquidation value of collateral is not sufficient to cover the outstanding liquidity borrowed, the ECB becomes an unsecured creditor in bankruptcy with the same priority as other unsecured creditors.[9]

3 Empirical evidence

In this section, we describe our data sets, and estimate the ex-ante differences in credit ratings and liquidity profiles. In addition, we characterise the funding structure and borrowing capacity of banks. Using these estimates, we present evidence that these differences lead to differential responses by banks to ECB's liquidity provision.

3.1 Data

To estimate the bank characteristics, we use the ECB's Individual Balance Sheet Items (IBSI) database. This database contains balance sheet data, such as total assets, equity and loans, for around 250 Monetary Financial Institutions (MFIs or Banks) in the euro area covering almost 70% of the euro area banking system. The IBSI dataset that we use has two main advantages compared to the datasets currently used in the literature. First, we can create bank level time series going back to August 2007 up to February 2015 at monthly frequency, while Bankscope data have a yearly (or quarterly) frequency. Finally, IBSI provides novel

---

[8] However, the ECB may at any time apply additional risk control measures at the level of individual counterparties if required to ensure adequate risk protection.

[9] Conceptually, this may tilt ECB to prefer that banks issue equity in bad states as opposed to debt, which is *pari passu*.

measures of bank's rates and volumes of newly issued deposits and loans to non-financial corporations and households. We will use these measures later to highlight the role of the funding channel and to calibrate our model.

Next, we match the IBSI data to four data sets. First, we use the ECB's Centralised Security Database (CSD) to construct a panel of bank-level yield of external bank debt to measure the bank spread between the bank debt rate and the ECB deposit rate. This will be helpful later to calibrate our model.

Second, we use the ECB's bank credit ratings data to identify banks that have at least one rating by the main rating agencies (Moody's, S&P and Fitch). The availability of ratings at bank level is limited for euro area banks. We define a bank's credit rating as the median of its long-term unsecured credit ratings. We assign a numerical value to each rating: 1 for AAA, 2 for AA+, and so on.

Third, we match all banks to the bank-level data on ECB borrowing and security-level data on collateral pledged with the ECB. These data are collected by the ECB to implement its credit market operations reporting the ECB borrowing by type of operation (i.e. MRO vs LTRO).

Fourth, we match our dataset to SNL European Financials (which has a smaller coverage) to collect data on dividends' payment and equity issuance for the publicly listed banks in our sample to calibrate our model later. Our match yields almost more than half of our sample.

Overall, we construct a balanced panel of 197 euro area banks. As may be seen from Panel A of Table 1, average bank size is euro $59,613$ million. About 75% of assets are loans and 18% of assets are fixed income securities. 66% of liabilities are financed with deposits with an average spread over the ECB deposit rate of 62 basis points, while 15% of liabilities are financed with debt with an average spread over the ECB deposit rate of 174 basis points. The banks are relatively highly levered, with an average ratio of equity to assets of 8%. About 39% of banks are located in the distressed countries (Cyprus, Greece, Ireland, Italy, Malta, Portugal, and Spain). Finally, we observe that the average credit rating is 5.5, or equivalently, a rating between A+ and A, the same average reported by Drechsler et al. (2016) but for a different set of banks.[10]

On average, about 43% of banks borrow from the ECB in a given month (see Panel B of Table 1). The average borrowing over assets per banks is almost 3%, including observations with zero borrowing, but the 90th percentile is over 9%. We also observe security-level information by bank on all collateral pledged with the ECB in terms of the pre and post-haircut market value of a banks' collateral. The latter gives its total borrowing capacity with the ECB. On average, 7% of collateral over assets is fixed income securities. Therefore, banks on average are over-collateralised when they draw liquidity from the ECB. The ECB data also reports the amount collateral pledged in non-marketable assets that are mainly non-financial corporations and consumer loans. On average, banks rely much less on non-marketable to finance their liquidity operations with the ECB.

On average, 1% of the banks issue equity in a given month with an average equity issuance over equity of almost 14% (see Panel C of Table 1). On average, 6% of the banks pay dividends in a given month with an average dividends' payment over equity of 4%.

3.1.1 Funding and liquidity profile

To assess the relation between the funding and liquidity position of euro area banks and its reliance on ECB liquidity, we compute a historical proxy for the Net Stable Funding Ratio (NSFR) based on the IBSI data using the approach developed by Hoerova et al. (2018) and also inspired by Bai, Krishnamurthy, and Weymuller (2018).[11] This will serve as a measure

---

[10] The entity in Drechsler et al. (2016) (who use Bankscope) is the banking group implicitly assuming that central bank liquidity can be re-allocated within the banking group. However, only single MFIs have access to National Central Banks (NCBs) liquidity facility and there is anecdotal evidence that national supervisors impeded banks transferring easily liquidity within the banking group during the euro area sovereign debt crisis.

[11] IBSI data is not as detailed as regulatory data is needed to compute exactly NSFR. However, Hoerova et al. (2018) show that for the period 2014 – 2016 using regulatory data to compute the actual NSFR their proxies are close to the actual ones. First, they have a correlation of 0.55 between the actual NSFR and their proxy. Second, when they compare the distribution of their proxies with the distribution of the actual values, they find that their estimates are on the conservative side. Finally, a Kolmogorov-Smirnov test indicates that there is no statistical difference between the distribution of the two series of data.

of the funding and liquidity profile of the banks.[12] The objective of NSFR is to enforce a minimum requirement on the bank's share of stable long-term funding to cover a fraction of its illiquid assets.

A full definition of NSFR and the way it is computed is provided in the Appendix, to conserve space. We report all the main asset and liability categories and the respective weights to compute the NSFR proxy in Table A-I of the Appendix. In principle, we could have used the liquidity coverage ratio (LCR). However, the LCR requires banks to hold enough liquid assets to cover a fraction of outflows of short term funding. We prefer NSFR for the following reasons: first, it proxies for long-term funding needs which we will document later with the data; and, second it is more "assumption free" while LCR requires modelling the expected outflows of the liabilities.

Panel D of Table 1 reports an average NSFR of 96%, slightly below the 100% required by the Basel regulation, but we observe a substantial cross-sectional variation. The median NSFR is just below the average NSFR, but a group of banks is well below the average showing a riskier funding profile (the 10th percentile is almost 59%). Finally, the group of banks in the top decile satisfied the Basel NSFR requirements during the Great Financial and euro area sovereign debt crisis.

3.1.2 Borrowing capacity

One key empirical challenge is to measure the bank's borrowing capacity with the ECB. In fact, the pledged collateral by a bank may not necessarily be representative of its assets' holdings. Public information about banks' asset holdings is extremely limited since these data are considered proprietary or are only available to bank regulators.[13] We overcome

---

[12] This measure cannot be computed for banks located in France. The IBSI asset and liabilities categories shown in Table A-I of the Appendix are not reported for banks located in France in the first part of our sample (July 2007 - April 2010).

[13] Drechsler et al. (2016) for example use information on bank holdings of distressed-sovereign debt published for the European bank stress tests. However, European banks conducted only three separate rounds of bank stress tests (March 2010, December 2010 and September 2011), the information is limited to bank holdings of distressed-country sovereign debt and the bank stress tests were only designed to include the largest banks in the euro area.

this limitation implementing a novel approach to gauge the bank's borrowing capacity with the ECB. We provide here a brief overview but Section A-I.2 of the Appendix provides step-by-step details about how we construct our borrowing measure.

For marketable assets, we use data on security-level portfolio holdings of euro area investors from the Securities Holding Statistics (SHS). The data are collected on a quarterly basis in the euro area since the first quarter of 2009. Securities in our sample are identified by a unique International Securities Identification Number (ISIN). Investors in the SHS are defined by sector and by country of domicile.[14] For each country, we compute how much the banking sector (MFI) holds a specific ISIN over its outstanding amount. Thus, we merge the SHS with data on the eligible securities published by the ECB to verify whether an ISIN in SHS is eligible for ECB liquidity operations and the haircut applied by the ECB if the security is eligible.[15] If the security is ineligible we set the haircut at 100%. Finally, we link the holdings data to IBSI to compute the aggregate ECB haircut on the main IBSI asset balance sheet items at MFI level on a monthly frequency. The borrowing capacity with the ECB is defined as the value of the asset balance sheet item (e.g. domestic sovereign bonds) at net of the ECB eligibility requirements and haircuts.

We follow a similar procedure for non-marketable assets, relying on the ECB eligibility criteria. This in turn, allows us to measure the overall borrowing capacity of each bank over time during $2009 - 2015$ and investigate the time-series and cross-sectional patterns of such measure. To ensure the accuracy of our borrowing capacity measure, we verify that our borrowing capacity measure at bank-month level on average does not exceed the total liquidity borrowed from the ECB by the same bank.

Our measure of borrowing capacity should be thought of as an upper bound on the banks' ability to draw liquidity at the ECB for two reasons. First, we do not know whether ECB-eligible marketable collateral has been pledged in the private repo and security lending

---

[14] There are six aggregate sectors: households, monetary and financial institutions (MFI), insurance companies and pension funds (ICPF), other financial institutions (OFI), general government, and non-financial corporations.

[15] See `https://www.ecb.europa.eu/paym/coll/assets/html/index.en.html`..

markets, therefore we cannot quantify the fraction of encumbered securities. Second, the use of non-marketable as collateral is generally perceived by counterparties costly compared with marketable assets. As previously documented, banks pledge only less than 1% of non-marketable assets (over assets) to collateralise their ECB funding (see Panel B of Table 1).

Panel E of Table 1 reports an average borrowing capacity (over assets) of almost 26%, but there is a significant cross-sectional variation in the borrowing capacity of the banks: the 10th percentile is around 6% while the 90th percentile is around is 46%. A similar pattern can be observed for the borrowing capacity computed on marketable assets that are mainly fixed income securities. The average is almost 13% and the 10th and 90th percentiles are respectively 0% and 25%.

3.2 Borrowing capacity and collateral policy of LOLR

Our borrowing capacity measure with ECB depends on the banks' holdings of fixed income securities and on ECB eligibility criteria and haircuts and potentially on other characteristics of the bank. In Table 2 we investigate the determinants of borrowing capacity by estimating the following regression model:

$$\text{Borr. capacity sec}_{i,t+1} = \beta_1 \text{Security holdings}_{i,t} + \beta_2 \text{ECB haircut}_{i,t} + \gamma X_{i,t} + \mu_i + \mu_t + \epsilon_{i,t}, \quad (1)$$

where Borr. capacity $\text{sec}_{i,t+1}$ and Security $\text{holdings}_{i,t}$ are scaled by assets of bank i. ECB $\text{haircut}_{i,t}$ is the implied ECB haircut that depends on the ECB haircuts at security-type weighted by the bank's security type holdings. Controls, $X_{i,t}$, include assets (in log), the capital ratio and the bank rating. We note that while rating is available for more than half of the banks, we can compute the borrowing capacity for the majority of the banks of our sample. All the explanatory variables are month-lagged. Our regression model also includes bank-fixed effects (μ_i) and month-fixed effects (μ_t). We double cluster the standard errors across these two dimensions.

Columns (1) – (4) present regressions in levels, and columns (5) – (6) report regressions based on the first-differences. We also estimate our specification interacting the holdings of marketable securities and the implied ECB haircut on marketable securities with post year-month indicator variables to identify the post Lehman crisis (September 2009 - April 2010), the post Greek crisis (May 2010 - November 2011) and the post 3−year LTROs (December 2011 - February 2015) periods in Columns (4) and (6).

The key common finding is that the borrowing capacity is positively correlated with the holdings of marketable securities and negatively correlated with the implied ECB haircut showing that our measure is affected by changes in the ECB eligibility criteria and haircuts. This effect is more pronounced during the Great Financial crisis when the ECB relaxed the credit threshold for marketable and non-marketable assets from A- to BBB- to expand the set of collateral (Column (4)). We also see that the effect of the holdings of marketable securities is also pronounced during the LTROs suggesting that banks increased their holdings which resulted in an increase of their collateral availability. In Column (3) we include country-time fixed effects to control for any country-specific trends. All these coefficients are statistically significant at the 1% level. Additionally, we observe that the rating coefficient is not statistically significant in all specifications suggesting that that riskier banks do not necessarily have a larger borrowing capacity to rely on ECB liquidity.[16] Finally, we find similar results when we estimate our specification in first-differences (Columns (5) and (6)).

3.3 Bank funding profile and reliance on ECB liquidity

We next empirically analyse the relation between the liquidity take-up at the ECB and the time-varying NSFR and borrowing capacity measures during the Great financial and the euro area sovereign debt crises. This exercise is also informative for the model specification in the next section to identify the main variables affecting the banks' borrowing decision at

---

[16] Please not that the decrease in the number of observations in Columns (3) – (7) is due to the availability of rating at bank level.

the central bank. We estimate the following regression model:

$$\text{ECB liquidity take-up}_{i,t+1} = \beta_1 \text{NSFR}_{i,t} + \beta_2 \text{Borr. capacity}_{i,t} + \gamma X_{i,t} + \mu_i + \mu_t + \epsilon_{i,t}, \quad (2)$$

where the controls $X_{i,t}$ includes assets (in natural logarithms), the capital ratio which may indicate a need to borrow from the central bank and the bank rating. All the explanatory variables are month-lagged. Our regression model also includes bank-fixed effects (μ_i) and month-fixed effects (μ_t). We double cluster the standard errors across the two dimensions. To measure the total ECB liquidity take-up, we use the log(ECB liquidity take-up + 1) to account for the banks that do not rely on ECB liquidity (see Columns (1)-(5) of Table 3). We also restrict our specification to the banks who participated to the financing operations, log(ECB liquidity take-up) (see Columns (6)-(7) of Table 3). In this way, we assess both the extensive and intensive margins of ECB borrowing.

The results show a strong negative relation between the NSFR and liquidity take-up, implying that banks with a higher NSFR were relying less on ECB liquidity, and a strong positive relation between the borrowing capacity and liquidity take-up as expected (Columns $(1)-(2)$). These results are not affected by the introduction of bank rating (Column (3)) which shows a positive coefficient consistent with Drechsler et al. (2016). Additionally, we investigate whether these results are driven by the distressed-countries and we report the results for banks located by non-stressed countries (Column (4) as in Drechsler et al. (2016)). We find similar results suggesting a strong relationship between the liquidity take-up at the LOLR and the funding profile and borrowing capacities of banks. The effects of NSFR and borrowing capacity are confirmed when we interact the variable with a post Great Financial crisis, Greek crisis and $3-$year LTROs month dummies (Column (5)). The effect of the borrowing capacity is more pronounced during the $3-$year LTROs. The results are unaffected when we restrict our specification to the banks who participated to the ECB financing operations (Columns $(6)-(7)$).

3.3.1 Bank ex ante funding profile and borrowing decision with ECB

We next ask whether banks with a *worse pre-crisis NSFR* rely more on the ECB liquidity during the Great Financial and euro area sovereign debt crisis. We follow Drechsler et al. (2016) and implement our analysis using a difference-in-differences regression framework. We address the potential endogeneity concerns by using our estimates of NSFR *before* the crisis began (August 2007). We also control for the rating and bank characteristics as the assets' size and the capital ratio as of August 2007 as in the previous specification.[17] Thus, all controls are measured as of August 2007, which mitigates the concern that bank borrowing choices are driven by changes in bank characteristics due to liquidity opportunity change. Our estimation controls for country × time fixed effects ($\mu_{j,t}$) to capture time-series variation that is common to all banks within a country j. Specifically, we estimate the following regression:

$$y_{i,t} = \mu_{j,t} + \beta_t^{NSFR}\mathrm{NSFR}_i^{2007} \times \mathrm{Post}_t + \beta_t^{Rat}\mathrm{Rating}_i^{2007} \times \mathrm{Post}_t + \epsilon_{i,t}, \tag{3}$$

where $y_{i,t}$ is ECB borrowing indicator (which takes on a value of 1 if a bank borrows from ECB), the amount borrowed from the ECB in natural logarithmic including and excluding observations with zero borrowing. Post_t is a set of year-month indicator variable to identify the post Lehman crisis, the Greek crisis and the $3-$year LTROs periods.

Table 4 presents the results. We find that banks with weak ex-ante funding profiles overall increased their ECB borrowing relative to banks with strong funding starting with the Great financial crisis after controlling for the rating or risk taking channel and other bank's characteristics (Columns $(1)-(4)$). The results are statistically significant at 1% level when we restrict our specification to non-distressed countries (Column 2 and 4). Overall, our results confirm and complement our previous analyses suggesting that the traditional role of ECB as LOLR cannot be dismissed. However, we find the effect of weak bank funding on

---

[17] We cannot control for the borrowing capacity with ECB because this measure can be computed since the first quarter of 2009.

ECB borrowing during the Greek crisis when we restrict our specification to actual borrowing (excluding observations with zero borrowing) both for the full sample and for the sample restricted to the non-distressed countries only (Columns (5) and (6)). We do not find any effect on the ex ante funding profile on the ECB borrowing during the 3−year LTROs suggesting that pre-3−year LTROs bank funding might have affected the borrowing decision. Consistent with Drechsler et al. (2016) we find that banks with lower rating increased their ECB borrowing relative to banks with a higher rating both in the Greek crisis and 3−year LTROs period, although the coefficients are not statistically significant when we restrict our specification to actual borrowing (Columns (5) and (6)).

3.3.2 Is NSFR driven mostly by banks' liabilities?

We then sort banks along the pre-crisis rating and NSFR using the median rating and the median NSFR as of August 2007. Figure A-IV of the Appendix provides a simple scatter plot of the NSFR and the rating. It is apparent that there is a very low correlation between the NSFR and the rating as of August 2007. This allows us to construct two groups of banks: 1) banks with low rating & low NSFR (LL) and 2) banks with high rating & high NSFR (HH).

Table 5 reports the mean, the standard deviation and the results of a mean t-test for the main asset and liabilities categories for the two groups of banks. All the asset and liability categories are scaled by total assets as of August 2007. The categories are based on the weights that are used for the NSFR computation (see Table A-I of the Appendix). The t-stat with a 95% confidence interval is 2.004.

LL banks are on average bigger than HH banks in terms of assets (€66, 934 vs €56, 033 million) but we also observe a large standard deviation for both groups (see Panel A). The t-test at 5% rejects the hypothesis that the means of assets are significantly different from each other. We also look at our dummy variable, D. non-distressed sovereign, that is equal to one when the bank does not belong to one of the euro area countries that went in financial troubles since April 2010. None of the two bank groups belongs to this group of countries.

Panel B in Table 5 examines potential differences in asset bank characteristics between the two groups. Banks do not hold cash or deposit cash with the ECB as of August 2007. Instead, the average holdings of government debt securities are 6.03% (HH) and 3.22% (LL) but the t-test at 5% rejects the hypothesis that the means are significantly different from each other. Bank assets mainly consist of corporate debt securities and loans, making up to 68.4% (70.19%) of total assets for HH (LL) banks in August 2007.[18] The t-test at 5% for each category rejects the hypothesis that the means of loans and corporate debt securities shares are significantly different from each other. The last category with a weight of 1 includes a heterogenous composition of assets that are not included in the previous categories and therefore we include all the main subcategories. We do not observe any substantial difference across these categories as well.

We then compute statistics and t-test for five mains sources of funding (see Panel C). The first category with a zero weight includes mainly funding with residual maturity of less than six months from financial institutions or without a state maturity. This category includes repo, unsecured funding and debt with a maturity below one year (i.e. commercial papers). Thus, we define this category as an unstable or risky source of funding. The average unstable funding ratio for LL is almost 44% and is more than double than the HH unstable funding ratio (22%). HH banks rely more on households deposits and long-term debt (21.77% and 26.12%) than LL banks (12.99% and 20.55%). However, the single t-tests do not confirm these differences between the two groups in terms of this funding structure. Finally, we do not observe any substantial difference in terms of equity between the two groups.

Overall, Table 5 suggests that the two groups differ mainly on their funding structures (or liability structures). The literature has tended to mainly emphasise the risk-taking channel of the asset side while we emphasise the funding channel. Table 5 also suggests to calibrate the model in terms of liability structure composition in August 2007 considering three main

---

[18] We sum over the categories MFI loans and corporate debt, loans with a maturity below 1 year, loans with a maturity below 5 year, and loans with a maturity above 5 year.

private debt contract-types: 1) unstable funding associated with a zero weight in the NSFR ratio; 2) stable funding associated with a weight above 0.9 in NSFR ratio and 3) secured debt.

4 A micro dynamic model of banking

4.1 Overview of the model

To understand the implications of our empirical findings for the banks' funding risk as well as its consequences for central bank (CB) borrowing, we now proceed to build a micro dynamic banking model, which centrally features the interaction between banks' funding structure and central bank liquidity. We first lay out the key mechanisms of our model. A formal development follows in the next sub-section. The model has two versions. The first version is one in which the banks do not have access to CB. This is our counterfactual. The second version is one in which the banks have access to CB. The complete solution is provided in Section A-I.4 of the Appendix.

The bank's asset portfolio is represented by A, consisting of loans and securities and is subject to shocks modelled by a Brownian motion process. The bank holds a cash balance denoted by $W > 0$. On the liability side, the bank has deposits in the amount dented by P^S. The deposits are remunerated at the risk-free rate r, and the aggregate coupon is $C^S = r \times P^S$.[19] In addition, it continuously rolls over additional non-deposit debt at the rate $m^D \times P^D$ by the issuance of new debt with identical principal value, coupon rate, and seniority to maintain the par value at P^D with an average maturity of m^D periods as in Leland (1998). Thus, the bank is exposed more to rollover risk when its uses non-deposit debt. This feature allows us to proxy the bank's NSFR: the larger the par value P^D the bank has to roll over the lower its NSFR ratio is.[20] Then, we can quantitatively assess the

---

[19] The deposits are senior in the priority structure. We enforce the necessary conditions to ensure that the deposits are risk-free when the bank is shut down by the resolution authorities.

[20] The rollover risk also depends on the average maturity m^D: the lower the maturity of the debt the bank

impact of a low NSFR ratio on the demand of CB liquidity that we have documented in the previous section.

We model the CB as follows. The CB liquidity facility acts as a credit line and a source of funding the bank can draw on at any time it chooses up to a limit. When the CB liquidity is activated ($W < 0$), we model the full allotment policy that ECB implements. We set the limit to a maximum fraction of the bank's asset portfolio A, so that the bank can borrow up to $(1 - \Theta) \times A$. Θ is set by the CB collateral policy and is average haircut on eligible assets as a percentage of all assets (eligible and ineligible) that has been measured with some care in previous section. In the counterfactual version of the model, the bank has no access to the CB and therefore $\Theta = 1$. The CB charges $r + s^{CB}$ which is borrowing rate against eligible collateral and s^{CB} is the penalty spread. Together, the pair $\{\Theta, s^{CB}\}$ captures the collateral policy of the CB in extending liquidity.

The CB lends to the bank only when it is solvent. We assume that bank's liquidation occurs if asset value falls to an exogenous solvency level A^B. The choice of A^B follows from minimum total capital requirements.[21] In addition, bank's equity holders might optimally decide to abandon the bank although the bank is still solvent according to the minimum total capital requirements.

The bank acts to maximise its equity value denoted by $E(W, A)$ that depends on the cash W and asset portfolio A. The bank optimally makes decisions on assets and liabilities. First, the bank chooses how much to invest or disinvest in asset portfolio A, but this investment or disinvestment is subject to adjustment costs. Second, the bank can decide how much cash to retain or pay dividends. Finally, when the bank runs out of cash, the bank can issue equity, but the issuance of equity is costly.

---

has to roll over the lower its NSFR ratio is.

[21] Suppose that ζ is the fraction of total assets that represents the minimum total capital requirements. The quantity, $A^B - P^S$ is the total capital comprising of equity and non-deposit debt. Then, $A^B - P^S = \zeta \times A^B$. This implies that $A^B = \frac{P^S}{1-\zeta}$.

4.2 Model development

We first describe the bank's asset portfolio and cash evolution accounting for bank's capital structure. Next, we introduce the bank's external equity issuance costs and its opportunity cost of holding cash. Finally, we state the bank optimality conditions. In Section A-I.4 of the Appendix we solve the equity value function deriving the boundary conditions and we outline our numerical procedure.

The bank's asset portfolio A follows the dynamics

$$dA_t = (-\underbrace{\frac{1}{\delta}}_{\text{Assets' maturity}} A_t + \underbrace{I_t}_{\substack{\text{Investment}\\ \text{policy}}})dt + \underbrace{A_t dX_t}_{\text{Loss or gain}}, \tag{4}$$

where $\delta > 0$ is the rate at which the asset portfolio matures. Thus, the average maturity of the existing stock is δ. The assets of the bank can be thought of as a portfolio of loans and non-loan assets such as debt securities.

The bank can increase or decrease the stock of its loans investing or disinvesting in the asset portfolio itself, I_t. This is a control variable at the bank's disposal: the bank can sell its loan portfolio in "bad states" to meet the liquidity needs, and expand its loan portfolio in "good states". We assume that the bank incurs the adjustment cost $g(I_t^*)$ in the investment process. As in the Q-theory of investment, the adjustment cost is convex and asymmetric to capture bank's information production costs about credit quality:

$$g(I_t) = (\psi^+ \mathbb{1}_{I_t \geq 0} + \psi^- \mathbb{1}_{I_t < 0}) I_t^2, \tag{5}$$

where $\mathbb{1}$ is an indicator function. A bank incurs screening and monitoring per-unit costs ψ^+ when it increases lending, and per-unit liquidation costs ψ^- when loans are reduced, where $\psi^- \geq \psi^+ \geq 0$. If $\psi^- > \psi^+$, then there is costly reversibility, since a bank would typically face higher costs to liquidate its investments rather than expanding them. This assumption is consistent with the view that the costs of breaking bank relationships may be higher than those associated with an expansion of lending to old as well as new customers.

The investment then satisfies the following first-order condition:

$$I_t = \frac{1}{2(\psi^+ \mathbb{1}_{I_t \geq 0} + \psi^- \mathbb{1}_{I_t < 0})} \left(\frac{E_W(W, A)}{E_A(W, A)} - 1 \right) \tag{6}$$

where $E_W(W, A)$ and $E_A(W, A)$ is the marginal value of equity with respect to cash and asset portfolio respectively.

The last term in Equation 4, $A_t dX_t$, describes the additional law of motion components of the asset portfolio, where dX_t is the bank's asset shock over time increment dt

$$dX_t = (r + \widetilde{\mu}^X)dt + \sigma^X dZ_t, \tag{7}$$

where Z_t is a standard Brownian motion. Thus, the parameters $\widetilde{\mu}^X$ and σ^X are the risk premium and the volatility of the asset shocks dX_t.

The bank's incremental operating profit cash flows dY_t over time increment dt is given by

$$\begin{aligned} dY_t = {} & \frac{1}{\delta} A_t dt - I_t^* dt - \underbrace{g(I_t^*)}_{\text{Investment cost}} dt \\ & - \underbrace{C^S}_{\text{Deposits coupon}} dt - \underbrace{C^D}_{\text{Debt coupon}} dt + \frac{1}{\underbrace{m^D}_{\text{Maturity}}} \left[\underbrace{D(W, A, m^D; s^D)}_{\text{Market value}} - \underbrace{P^D}_{\text{Principal}} \right] dt, \end{aligned} \tag{8}$$

where $(1/\delta)A_t$ is the repayment of maturing loans, I_t^* is the optimal investment in new loans if it is positive, or the amount of cash obtained by liquidating loans if it is negative, and $g(I_t^*)$ is the additional adjustment cost that the bank incurs in the investment process.

The last terms are related to the debt service. Deposits are the most important source of funds for banks to finance their assets. Deposits are risk-free, the fair interest rate on deposits is the risk-free rate r. Thus, $C^S = r \times P^S$.

We model the external debt as follows. A constant fraction m^D of the outstanding debt matures at any instant of time. C^D is the coupon of the external debt with face value P^D. Thus, the bank retires the debt at the rate $m^D \times P^D$ but it continuously replaces it by the issuance of new debt with identical principal value, coupon rate, and seniority. New debt is issued at market value which may diverge from par value as in Leland and Toft (1996). Thus the net refunding cost occurs at the rate $m^D \times (P^D - D(W, A, m^D; s^D))$ where $D(W, A, m^D; s^D)$ is the market value of the total debt given the current value of cash W_t and asset portfolio A_t and s^D is the credit spread. It is important to note that when $D(W, A, m^D; s^D) < P^D$ equity holders face negative cash flows. Hence, the rollover can be expensive for the bank. This possibility is illustrated in Figure A-V of the Appendix.

Ignoring closure and debt repurchase, the average maturity of eternal debt is then $1/m^D$ years. This way of modelling the debt allows us to examine two important issues. First, we can compare the maturity of the debt contract with the maturity of the loan book, δ, to quantify the extent of maturity transformation performed by the bank. Second, we can explore the relationship between the share of short-term interbank liabilities of the bank and the bank's reliance on cash buffers and CB liquidity.

We next turn to the bank's cash buffers. Let W_t denote the bank's cash buffer at time t. When $W_t > 0$, the bank is in the cash region, wherein the bank holds internal liquidity. The rate of return that the bank earns on its cash buffer is the risk-free rate r minus a carry cost $\lambda > 0$ that captures in a simple way the agency costs that may be associated with free cash in the bank. Intuitively, when the cash buffer is very high, the bank is better off paying out the excess cash to shareholders to avoid the cash-carrying cost. The benefit of a payout is that shareholders can invest at the risk-free rate r, which is higher than $r - \lambda$, the net rate of return on cash within the bank. However, paying out cash also reduces the bank's cash balance, which potentially exposes the bank to current and future underinvestment and future reliance on CB liquidity. The tradeoff between these two factors determines the optimal payout policy. Thus, the bank chooses how much cash ($W > 0$) to retain when $\overline{W}(A) > W$ or pay in dividends in the amount $W - \overline{W}(A)$, when $\overline{W}(A) < W$. Here $\overline{W}(A)$

is endogenous to the optimisation problem. Let U_t be the bank's cumulative payout to shareholders up to time t, and by dU_t the incremental payout over time interval dt.

If the bank exhausts its credit line with the CB, it has to either raise external funds via costly equity issuance to continue operating, or liquidate its assets. The bank can issue equity, but the process is costly due to informational asymmetry as discussed in Myers and Majluf (1984) and incentive problems. As in the current literature we model such costs in reduced form: when the bank chooses to issue external equity H, it incurs a fixed cost ϕ and a proportional cost to the amount of equity raised $\gamma \times H$. These costs imply that the bank will optimally tap equity markets only intermittently, and, when doing so, it raises funds in lumps, consistent with observed bank's behaviour in our data. $\widetilde{W}(A)$ represents the level of cash after post-issuance of equity and at $\widetilde{W}(A)$ the marginal benefit for the bank of holding an additional unit of cash exceeds one by an amount equal to the marginal cost of issuing new equity.

Alternatively, the bank could adjust its private debt level in response to a deterioration of its cash policy. We are not extending the model in this direction for the following reasons. First, we empirically observe that the capital structure composition for HH and LL banks was pretty stable over time in our sample (see Figure A-VI in the Appendix). Second, the bank in our setting has access to LOLR with associated collateral policies. The bank dynamically changes the level of CB debt in its liability structure, relative to its private debt and deposits level to manage its "illiquidity".

In some situations, the bank may prefer voluntary liquidation. There are two distinct features of our model that characterise this choice. First, the equity holders' decision of whether to abandon the bank or not is influenced by its financial considerations and the prospect of having to incur external equity issuance costs in the future. Second, all else equal, the rollover costs in debt security markets when $P^D > D(W, A, m^D; s^D)$ ought to be an additional inducement to abandon the bank. Therefore, one would expect that the prospect of having to incur external equity issuance costs and rollover costs in debt security market would lower the banks equity valuation and result in a higher abandonment hurdle in terms of the asset portfolio A. Therefore, we need to identify the abandonment hurdle $A^*(W)$ at which equity holders are just indifferent between abandoning the bank or not. We denote with τ the stochastic liquidation time.

The dynamics of the state variable W in the cash region ($W_t \geq 0$) is

$$dW_t = \underbrace{dY_t}_{\substack{\text{Bank's}\\\text{profits}}} + (r - \underbrace{\lambda}_{\substack{\text{Cost of}\\\text{holding cash}}})W_t - \underbrace{dU_t}_{\substack{\text{Dividends'}\\\text{payment}}} + \underbrace{dH_t}_{\substack{\text{Equity}\\\text{issuance}}} . \tag{9}$$

When the bank borrows from the CB ($W_t < 0$), the dynamics of the state variable W evolves similarly as W_t does in the cash region

$$dW_t = \underbrace{dY_t}_{\substack{\text{Bank's}\\\text{profits}}} + (\underbrace{r + s^{CB}}_{\substack{\text{Cost of}\\\text{borrowing cash}}})W_t - \underbrace{dU_t}_{\substack{\text{Dividends'}\\\text{payment}}} + \underbrace{dH_t}_{\substack{\text{Equity}\\\text{issuance}}} , \tag{10}$$

where s^{CB} denotes the interest rate spread over the risk-free rate.

The credit region is delimited by two exogenous boundaries. First, when bank's asset value drops to a low threshold

$$A^B = l \times A_0, \tag{11}$$

the bank has to close down and liquidate its assets incurring in additional dead-weight losses denoted by the fraction l. A_0 denotes the asset portfolio value at time 0.[22]

Second, the bank can exhaust its maximal borrowing capacity with the CB when

$$W_t = \underbrace{-(1 - \underbrace{\Theta}_{\text{CB Haircut}}) \times A_t}_{\text{Borrowing capacity}}, \tag{12}$$

but the bank has still the option to raise new funds through external equity issuance or

---

[22] By minimum total capital requirements, $A^B = \frac{P^S}{1-\zeta}$ as noted earlier. This implies that the dead-weight loss factor $l = \frac{P^S}{A_0} \times \frac{1}{1-\zeta}$ is the fraction of deposits over assets, grossed up by the minimum capital requirements.

to liquidate its assets.

The bank chooses its investment I, payout policy U and external financing policy H to maximize shareholder value subject to i) the asset portfolio equation (4), ii) the cash equations (9) and (10), and iii) the boundary conditions (see Section A-I.4 of the Appendix):

$$\max_{I,U,H} \mathrm{E}\left[\int_0^{\tau} e^{-rt}\left(dU_t - dH_t - \Phi(dH_t)\right) + e^{-r\tau}\max(W_\tau + l \times A_\tau - P^D - P^S, 0)\mathbb{1}_{\tau=\min(\tau_l,\tau_d)}\right]. \tag{13}$$

The first term is the discounted value of net payouts to shareholders where U_t denotes the cumulative costs of external financing up to time t, and $\Phi(dH_t)$ denotes the incremental costs of raising incremental external funds dH_t. The second term is the discounted value from liquidation. The liquidation occurs in two circumstances: i) default triggered by regulatory authorities $\tau = \tau_d$; or ii) when equity holders prefer liquidation instead of issuing equity $\tau = \tau_l$. Note that equity issuance hurts the value of existing equity holders.

5 Calibration, model solution and implications

In Section 5.1, we discuss how we calibrate the model's parameters and we provide intuition for how parameters are identified. We then provide the model solution in Section 5.2. We study two cases. First, we consider the case in which the bank has no access to the CB ($\Theta = 0$). Then, we consider the case in which the CB is present ($\Theta > 0$). In Section 5.3, we provide implications for borrowing at LOLR, default probability, investment, payment of dividends and equity issuance for HH and LL-type banks. We also examine a tighter borrowing capacity than in the base scenario by modelling borrowing capacity based only on the fixed-income security holdings.

5.1 Parameters and moments

We use the stylised facts reported in Table 5 to calibrate the model to the liability structure composition in August 2007 by considering three main private debt contract-types: i) unstable wholesale funding associated with a 0, 0.5 and 0.9 weight in the NSFR ratio and the overnight households deposits; ii) stable funding associated with a weight above 0.9 in NSFR ratio and consists of households deposits, excluding overnight households deposits, and non-financial corporation deposits with a time-to-maturity above one year; and iii) secured debt with a time-to-maturity above one year. This calibration implies that we have two debt contract-types subject to rollover risk. The model solution provided in Section A-I.4 of the Appendix accounts for this extension.

Panel A of Table 6 provides the different composition in terms of asset and liability characteristics. Thus, $t = 0$ in the model corresponds to August 2007. We rescale the total assets value to 100 for convenience. According to Table 5, banks hold a small amount of cash that can be approximated by 1 over assets. As a result, we set the asset portfolio A_0 at 99 for both groups.

For the capital structure, we impose the equity and debt as reported in Table 5. We set the equity E_0 at 6% (7%) and debt P_0^D at 26% (21%) for HH (LL) banks, respectively. When we sum over the share of liabilities over assets with a weight below 0.95, we obtain a share of unstable deposits P_0^U of 43% (62%) for HH (LL). Finally, the amount of stable deposits level P_0^S sums up to 100.

The other model parameters are reported in Panel B of Table 6. Our dataset starts in July 2007 when we also differentiate the two groups of banks in terms of asset and liability characteristics. However, the model parameters should be inferred over a longer period. Thus, the parameters are computed over the sample July 2007 - April 2010. The latter date coincides with the beginning of the euro area sovereign debt crisis.

We set r at the average ECB deposit rate of 1.25% over the sample July 2007 - April 2010, while we set the central bank penalty s^{CB} at 0.50% to match the average ECB refinancing rate over the same period (1.75%).

We set the loans' maturity parameter δ at 9.17 (9.36) years for HH (LL) banks based on the weighted average loans' maturity in August 2007. The weight is the nominal amount of loans at bank level. If we use the sample over the period July 2007 - April 2010, the figures are slightly different: 9.04 years for HH group and 9.40 years for LL. This suggests that loans' maturity is highly persistent over time and did not change during the Great Financial crisis.

We use a panel regression on the asset volatility of households and non-financial corporations (NFC) loans that includes investment in new loans over assets as explanatory variable to estimate σ^X. The details of this calibration is described in Section A-I.3 of the Appendix. We estimate a volatility parameter of 8.99% (9.31%) for the HH (LL) group over the period July 2007 - April 2010. Thus, we do not observe any substantial difference in terms of asset risk between the two groups.

From the literature we pick three parameters. The shareholders require a risk premium $\widetilde{\mu}^X$ which we set to 3.3%, consistent with a beta of banking sector equal to 0.7 (Fahlenbrach, Prilmeier, and Stulz (2012), Fahlenbrach, Prilmeier, and Stulz (2018)) and the historic average of equity premium. Finally, we set the unit price of loan investment and disinvestment to 4% and 5% respectively following De Nicolo, Gamba, and Lucchetta (2014).

For the capital structure, we measure the average time-to-maturity m^U and spread s^U of the unstable funding looking at all debt securities with a time-to-maturity below one year issued by the banks belonging to the two groups. We use the Centralised Securities Database that provides information on all individual securities issued in the European Union but the data start in 2009. The average time-to-maturity of the unstable funding, m^U, is 0.19 (0.25) years for HH-type (LL-type). The average spread s^U is slightly negative (-0.25%) for HH-type, while it is 0.62% for LL-type over the same period. We use the same approach to calibrate the parameters of the secured debt. The average time-to-maturity of the secured debt, m^D, is 3.46 (3.46) years for HH-type (LL-type). The mean spread s^D is 0.36% (0.93%)

for HH-type (LL-type) over the same period. Our estimates of the spreads of unstable deposits and secured debt complement our previous empirical findings. LL-type banks with a riskier capital structure proxied by the NSFR ratio on average relied more on ECB liquidity and faced a higher cost of funding during the Great Financial crisis period.

Finally, the LL-group (HH-group) has an average borrowing capacity over assets with the CB, $1 - \Theta$, of 33.51% (28.18%) over the period January 2009 - April 2010. We also explore the implications for our main results of setting $1 - \Theta$ at zero implying no access to the CB liquidity facility. Thus, we change $1 - \Theta$ from 33.51% (28.18%) to 14.41% (15.25%) where the latter one is based on the average borrowing capacity over assets computed on fixed-income security holdings.

The other parameters have to be calibrated by solving and simulating the model (see Table 7). For each bank type, we simulate data $50,000$ times generating 15 years of monthly data after solving the model. For each variable of interest, we report the average of the simulated database and we also report the 10th percentile, median and 90th percentile in brackets for the continuous variables. We select the liquidation parameter l, the opportunity cost of cash λ, the fixed cost of issuing equity ϕ and the marginal cost of issuing equity γ to match the historical default rate of the rating category, the dividends' payment frequency and the dividends' payment over equity, and the frequency of equity issuance and the equity amount issued over equity. For the historical default rate of the rating category, we observe that the Standard&Poor's global financial services average cumulative default rate for Europe is 0.43% over a 14 year horizon for AA rating (HH-type), while it is 0.49% (3.32%) for A (BBB) rating (LL-type).[23] Finally, for the equity amount issued and the frequency of equity issuance we do not distinguish between the two bank groups due to few observations we have of actual equity issuance (see Table 1).[24] Therefore, the fixed cost of issuing equity ϕ and the marginal cost of issuing equity γ are identical across the two bank groups.

---

[23] See Table 15 of the Standard&Poor's report on "Default, Transition and Recovery: 2020 Annual Global Financial Services Default and Rating Transition Study" at `https://www.spglobal.com/ratings/en/research/articles`.

[24] For the entire sample we have almost one hundred equity issuance observations.

While our model is highly stylised, it does allow us to match the CB borrowing over assets distribution and the average cumulative default rate of the two groups. Among the five moments we target, the simulated model has difficulty in generating a distribution that is close to the observed one for two moments. First, we underestimate the dividends payment over equity moment. The main reason is that the optimal payout strategy for shareholders is of barrier type: dividends are distributed to maintain cash at or below $\overline{W}(A)$. Differently, the dividend payout in the data follows a lump sum distribution. Second, we overestimate the equity issuance over equity moment keeping a plausible range for the parameters γ and ϕ. We would like to raise two caveats. First, the empirical and the simulated moment are not directly comparable. In the results obtained using simulated data, the ratio is computed using the market value of the equity $E(W, A)$, while equity in the data mainly reflects the full amount of capital raised over time recorded at the original value. Second, as previously discussed, bank equity issuance in our data is also rare (see Table 1).

5.2 Model solution

The economic analysis of the two-dimensional problem is significantly enriched, as the bank takes into account not only of its current stock of internal funds W but also of the information about its asset portfolio A. Despite the significantly more complex formulation of the two-dimensional problem, we are still able to provide an intuitive analysis of this problem.

To gain some intuition on the model solution we solve the model without and with the CB. The model solution is for the HH-type and is based on the parameters previously discussed. Figures 2, 3, 4 and 5 graphically represent the numerical solution of the model.

Figure 2 refers to the solution without the CB. The continuous blue line refers to the dividend payout boundary $\overline{W}(A)$: when $W > \overline{W}(A)$ the bank pays dividends in the amount $W - \overline{W}(A)$. The boundary is convex with respect to asset portfolio A and hence the bank needs to hold a lower stock of internal funds W as the bank's asset portfolio A grows. The red dashed line represents the level of cash after post-issuance of equity $\widetilde{W}(A)$. The boundary starts at A^* (point $+$) that identifies the equity issuance - liquidation hurdle. For $A < A^*$ equity holders prefer liquidation instead of issuing costly equity. The yellow area delimited by the dividend payout boundary $\overline{W}(A)$ and the axis $W = 0$ defines the inaction region and identifies the internal financing region of the bank without the CB.

When we introduce the CB, the bank can borrow but the amount of CB liquidity is limited by two exogenous boundaries. The first one is the solvency boundary defined by Equation (11). The second boundary defines the borrowing capacity setting the limit to a maximum fraction of the bank's asset portfolio A, so that the bank can borrow up to $(1 - \Theta) \times A$. The blue area when $W < 0$ defines the borrowing region with the CB (see Figure 3). In the presence of the CB, the abandonment hurdle A^* increases because the bank is more levered.

Figure 4 shows three simulated paths for the cash variable W with the CB. The first path (dashed red line) plots the scenario where the bank issues equity several times when cash flow shocks deplete the liquidity the bank can borrow from the CB ($\blacksquare$ indicates where the bank raises equity). As previously discussed, the bank issues new equity paying the fixed cost ϕ and the marginal cost γ to replenish its liquidity W_t from zero to $\widetilde{W}(A)$. In all cases where the bank issues equity for purposes of replenishing its liquidity it chooses different financing levels because each time it has different levels of asset portfolio A when it exhausts its liquidity. Figure 5 shows the corresponding simulated path for the asset portfolio A (dashed red line). The second cash path (continuous blue line) of the top panel plots the scenario where the bank pays dividends several times ($\bullet$ indicates where the dividends are paid). The optimal payout policy consists in distributing dividends to maintain liquid reserves at or below the target level $\overline{W}(A)$ that depends on the level of assets A. The third cash path (dashed-dotted black line) illustrates the case when the bank defaults: this occurs when the bank borrows from the CB and for a low level of the asset portfolio.

Bank's equity holders might optimally decide to abandon the bank although the bank is still solvent according to the exogenous solvency threshold we impose. There is a distinct feature of our model that characterise this choice. As in Bolton, Chen, and Wang (2011), Décamps et al. (2011) and De Nicolo, Gamba, and Lucchetta (2014), the equity holders' decision of whether to abandon the bank or not is influenced by its financial considerations and the prospect of having to incur external equity issuance costs in the future. But, all else equal, in our model the possibility of rollover costs in debt security market ought to be an additional inducement to abandon the bank. To illustrate this point, in Figure 6, we also plot the optimal solution when the bank does not face rollover risk on unsecured deposit and debt for the counterfactual case for simplicity.[25] This case also highlights how maturity intermediation affects bank's decision to manage internal funds. One can see that the prospect of having to incur debt security market losses results in an abandonment hurdle in terms of the asset portfolio A and therefore equity holders will not issue equity if the asset portfolio falls below it. Importantly, the equity holders when facing rollover risk optimally choose to rely more on internally generated funds implying a higher dividend boundary and as result they will issue a larger amount of equity when they will run of cash implying a higher equity issuance boundary.

5.3 Central bank borrowing, solvency, equity issuance and dividends' payment

We provide comparative statics varying the CB borrowing capacity and the CB penalty spread. For the base scenario we consider the larger value of the borrowing capacity based on loans and fixed income securities as reported in Table 6. For the HH (LL)-type the borrowing capacity, $1-\Theta$, is 28.18% (33.51%). We then consider a tighter borrowing capacity measure only based on fixed income securities: 15.25% (14.41%) for HH (LL)-type. The third scenario is the counterfactual with no access to the central bank. Therefore $1-\Theta = 0\%$. The CB penalty spread rate s^{CB} is set at 0.5% that is the one ECB charges over the deposit rate when the bank borrows. We consider also the case where the spread is equal to zero to proxy

---

[25] We set $(1/m^D) = (1/m^U) = 0$.

for the cheap funding of the 3−year LTROs.[26] Table 8 provides the numerical results.

With a tighter CB borrowing capacity, the average CB borrowing over assets implied by the simulation exercise is lower: the borrowing decreases to 0.65% (1.06%) from 1.68% (3.79%) for HH (LL)-type (see Column (1)). If the CB decreases the the penalty spread s^{CB} to zero the average CB borrowing over assets increases for both groups.

The endogenous liquidation-equity hurdle (W^*, A^*) is affected by the CB borrowing capacity (see Column (2)). In the presence of the CB, the abandonment hurdle A^* increases because the bank on average relies more on CB liquidity. As a result, the bank is more levered and the bank's default likelihood increases (see Column (3)). For our set of parameters, conditional on choosing to raise equity, the bank with access to the CB issues more equity than a bank in the counterfactual case. Hence, the liquidation hurdle $A^*(W^*)$ increases when liquidity decreases in the borrowing region, $W < 0$. Hence, inefficiently liquidation occurs in a larger region.

Finally, access to CB liquidity also substantially improves the bank's investment problem (see Column (4)). In the presence of CB, the bank's investment-asset ratio at (W_0, A_0) is 6.91% (7.92%) for HH (LL-) type which is higher than 6.18% (6.81%) when the bank is about to run out of cash and has no access to CB liquidity.

Next, we turn to the effect of the CB borrowing capacity and penalty rate on equity issuance and dividends' payment. Table 9 provides the numerical results.

The equity value increases in the presence of CB and when the borrowing capacity is larger (see Column (1)). Column (2) also summarises the implied equity ownership dynamics that follow from the bank's decisions over the simulated paths of W and A. Under the simulated paths, we can highlight the dynamics of equity dilution by keeping track of the equity ownership of the original investors who have stayed with the bank since its inception $(t = 0)$. Appendix A-I.4.4 characterises the equilibrium fraction of the newly issued equity held by outside investors when the bank incurs external financing costs as it raises equity. Given

---

[26] The bank could borrow liquidity for three year at the lending rate that would be applied over the same horizon.

that the bank already starts out with a relatively low cash stock of $W_0 = 1$ it is optimal for the bank to wait until its borrowing capacity with the CB is entirely exhausted, thus deferring costly external equity issuance. In fact, the equity issuance is less frequent in the presence of the CB (see Column (3)). As a result, the original owners are diluted down to an average ownership stake of 97.33% (95.01%) with the CB for HH (LL)-type. In the counterfactual scenario, the HH-type bank's original owners only retain an average stake of 87.37%. Interestingly, the original owners of the LL-type bank benefit more of having access to CB liquidity. The average ownership is barely affected because they retain on average 95.01% share of the bank. Instead, they retain on average 80.41% share of the bank in the counterfactual. The main reason is that the owners of the LL-type bank issues more equity conditional on choosing to raise equity due to the riskier capital structure. Finally, dividend payment is more frequent in the presence of the CB because the bank significantly less cash when it has access to CB liquidity (see Column (4)).

6 Conclusion

Using novel data sets, our paper provides a number of new empirical results: we show that banks which are ex-ante weakly capitalised *before* the crisis increase their borrowings at ECB *after* the crisis. In addition, banks with ex-ante lower liquidity profiles rely more on LOLR after controlling for their credit ratings. We provide estimates of borrowing capacities of banks at the ECB, and document significant cross-sectional variations in borrowing capacities. Finally, we show that LL banks with lower credit ratings and lower ex-ante NSFR differ from HH banks mostly on their funding structures: this difference affects the way they respond to ECB liquidity provision.

We develop a dynamic model of CB liquidity provision to banks, which face frictions in loan portfolio adjustments, equity issuance, and closures resulting from violations of minimum capital requirements. Banks manage their liquidity by i) building cash buffers, ii) through equity issuance, iii) optimally sizing their loan portfolio and iv) by accessing LOLR. We show that the ability to access CB liquidity has both potential positive and negative implications. On the positive side, the size of the loan portfolio is higher when the banks have access to CB liquidity than when they do not. The incremental effect depends crucially on the level of leverage of the bank and the extent of maturity transformation undertaken by the bank. On the negative side, the existence of CB liquidity facilities causes the banks to hold lower optimal cash buffers. By substituting risky assets for cash the banks increase their overall riskiness. In addition, we show that the access to LOLR decreases the banks' incentives to issue equity, or to cut dividends. Through LOLR policy simulations we show that by increasing the haircuts and penalty rates banks can be incentivised to pursue more conservative dividend policies.

We have not modelled a general equilibrium framework: rather, we have worked out in detail how banks will respond when they have access to LOLR and have compared their response with the counterfactual when they do not have access to LOLR. We believe that this is an important step towards building a general equilibrium analysis.

7 Tables

Table 1: **Summary statistics -** This table provides bank-level summary statistics from July 2007 to February 2015. The sample comprises 197 euro area banks. The variables are for the entire sample except debt spread, rating, dividends' payment, equity issuance and borrowing capacity.

	Mean	Sd	p10	p50	p90	N
A - Bank characteristics						
Assets (euro mil.)	59,613	89,149	4,123	28,358	154,845	18,321
Loans / assets (%)	75.48	16.57	57.14	76.63	96.53	18,204
Securities / assets (%)	18.32	14.18	0.21	16.68	36.02	18,321
Deposits / assets (%)	65.69	21.02	38.56	69.31	88.84	18,321
Spread deposits (%)	0.62	0.88	-0.41	0.57	1.72	14,393
Debt / assets (%)	15.14	17.80	0	9.51	37.78	18,297
Debt spread (%)	1.74	1.20	0.35	1.63	3.18	6,679
Capital ratio	8.01	6.11	2.56	6.77	13.8	18,321
Distressed country (yes = 1)	0.39	0.49	0	0	1	18,321
Rating	5.52	2.26	3	5	8.5	7,703
B - ECB borrowing						
Borrowing (yes = 1)	0.43	0.49	0	0	1	18,321
Liquidity / assets (%)	2.72	5.15	0	0	9.29	18,321
Marketable / assets (%)	7.35	13.48	0	3.51	15.77	18,321
Non-marketable / assets (%)	0.78	2.01	0	0	2.17	18,321
C - Equity issuance and dividends per month						
Equity issuance (yes = 1)	0.01	0.10	0	0	0	10,602
Equity issuance / equity (%)	14.55	20.64	2.20	8.47	28.61	112
Dividends payment (yes = 1)	0.06	0.24	0	0	0	10,602
Dividends pay / equity (%)	3.99	4.28	0.61	2.62	9.63	634
D - Funding profile						
NSFR (%)	96.44	39.95	59.16	91.59	130.82	18,321
E - Borrowing capacity						
Borrowing capacity / assets (%)	26.10	15.64	6.04	24.83	46.70	14,775
Borrowing capacity sec. / assets (%)	12.80	9.94	0.09	11.32	25.52	13,113

Table 2: **Borrowing capacity and bank characteristics -** This table examines the effect of banks' holdings of fixed income securities, ECB eligibility criteria and haircuts on borrowing capacity with ECB. The unit of observation is at bank-month level. Post Lehman, Post Greek and Post 3y LTRO are indicator variables for the periods from October 2008 to April 2010, May 2010 to November 2011 and December 2011 to February 2015. Columns (1) – (3) and (5) – (7) include month fixed effects. Column (4) includes country x time fixed effects. Columns (2) – (5) include bank fixed effects. Standard errors in parentheses are double-clustered at the bank and month levels in Columns (2) – (5). Standard errors in parentheses are clustered at the month level in Columns (1) and (6) – (7). $***$ Significant at the 1% level, $**$ significant at the 5% level, and $*$significant at the 10% level.

	(1) Level	(2) Level	(3) Level	(4) Level	(5) Level	(6) First-diff.	(7) First-diff.
Holdings mark sec.	0.574***	0.615***	0.535***	0.533***		0.522***	
ECB elig. & haircuts	-0.084***	-0.074***	-0.149***	-0.117***		-0.171***	
Holdings mark sec. x Post Lehman					0.537***		0.489***
Holdings mark sec. x Post Greek					0.535***		0.542***
Holdings mark sec. x Post 3y LTRO					0.516***		0.545***
ECB elig. & haircuts x Post Lehman					-0.152***		-0.165***
ECB elig. & haircuts x Post Greek					-0.154***		-0.182***
ECB elig. & haircuts x Post 3y LTRO					-0.138***		-0.181***
Rating			0.098	0.002	0.087	-0.043	-0.041
Assets (log)	0.012	0.744	0.500	0.046	0.414	-0.435	-0.560
Capital ratio	-0.285***	-0.067	-0.172**	-0.206***	-0.177**	0.030	0.026
Obs.	11,814	11,814	4,621	4,621	4,621	4,507	4,507
R-squared	0.769	0.939	0.955	0.967	0.955	0.422	0.428
Bank FE		Yes	Yes	Yes	Yes		
Time FE	Yes	Yes	Yes		Yes	Yes	Yes
Time x Country FE				Yes			

Table 3: **Bank funding profile, borrowing capacity and ECB borrowing -** This table examines the effect of NSFR, median rating and borrowing capacity with ECB on ECB borrowing. The unit of observation is at bank-month level. The dependent variable is the amount borrowed from the ECB in natural logarithmic including (Columns (1) – (5)) and excluding observations with zero ECB borrowing (Columns (6) – (7)). Post Lehman, Post Greek and Post 3y LTRO are indicator variables for the periods from October 2008 to April 2010, May 2010 to November 2011 and December 2011 to February 2015. Columns (2) – (7) include bank and month fixed effects. Column (1) includes month fixed effects. Standard errors in parentheses are double-clustered at the bank and time levels in Columns (2) – (7). Standard errors in parentheses are clustered at the month level in Column (1). $***$ Significant at the 1% level, $**$ significant at the 5% level, and $*$significant at the 10% level.

	(1) All	(2) All	(3) All	(4) Non-distr. sovereign	(5) All	(6) All	(7) All
	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq.)	Log (Liq.)
NSFR	-0.004***	-0.022***	-0.032***	-0.033***		-0.014***	
Borrowing capacity	0.045***	0.088***	0.113***	0.105*		0.051***	
Rating			0.195**	0.631***		0.069**	
NSFR x Post Lehman					-0.040***		-0.019***
NSFR x Post Greek					-0.027***		-0.006
NSFR x Post 3y LTRO					-0.032**		-0.011***
Borr. capacity x Post Lehman					0.114***		0.033**
Borr. capacity x Post Greek					0.083**		0.047**
Borr. capacity x Post 3y LTRO					0.143***		0.076***
Rating x Post Lehman					-0.077		-0.059
Rating x Post Greek					0.263**		0.082**
Rating x Post 3y LTRO					0.127		0.060
Assets (log)	0.814***	2.260***	2.864***	2.510*	2.864***	2.311***	2.306***
Capital ratio	0.066***	0.041	0.094**	0.095	0.094*	0.036	0.051*
Obs.	12,916	12,916	4,848	2,873	4,848	2,220	2,220
R-squared	0.148	0.644	0.650	0.549	0.660	0.825	0.834
Bank FE		Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4: **Ex ante bank funding profile and ECB borrowing -** This table examines the effect of NSFR and median rating as of August 2007 on ECB borrowing. The unit of observation is at bank-month level. The dependent variable is a ECB borrowing indicator (which takes on a value of 1 if a bank borrows from ECB) (Columns (1) – (2)), the amount borrowed from the ECB in natural logarithmic including (Columns (3) – (4)) and excluding observations with zero ECB borrowing (Columns (5) – (6)). Post Lehman, Post Greek and Post 3y LTRO are indicator variables for the periods from October 2008 to April 2010, May 2010 to November 2011 and December 2011 to March 2015. Columns (1) – (6) include country-time fixed effects. Standard errors in parentheses are clustered at the bank level. $***$ Significant at the 1% level, $**$ significant at the 5% level, and $*$significant at the 10% level.

	(1) All	(2) Non-distr. sovereign	(3) All	(4) Non-distr. sovereign	(5) All	(6) Non-distr. sovereign
	Borr. indicator	Borr. indicator	Log (Borr. + 1)	Log (Borr. + 1)	Log (Borr.)	Log (Borr.)
NSFR 2007 x Post Lehman	-0.001	-0.003***	-0.011*	-0.034***	-0.017***	-0.024***
NSFR 2007 x Post Greek	0.000	-0.001	0.003	-0.008	-0.012**	-0.029***
NSFR 2007 x Post 3y LTRO	0.001	-0.001	0.007	-0.006	0.001	-0.010
Rating 2007 x Post Lehman	0.011	0.001	0.073	-0.040	-0.057	-0.077
Rating 2007 x Post Greek	0.023**	0.025**	0.165**	0.175**	-0.007	0.064
Rating 2007 x Post 3y LTRO	0.014	0.029***	0.104	0.210***	0.038	0.061
Assets 2007 (log)	0.090***	0.006	0.960***	0.291**	0.687***	0.650***
Capital ratio 2007	0.000	-0.000	0.005	-0.004	0.015	0.018
Obs.	11,067	6,045	11,067	6,045	4,871	2,310
R-squared	0.317	0.358	0.392	0.374	0.654	0.549
Time x Country FE	Y	Y	Y	Y	Y	Y

Table 5: **Balance sheet characteristics of High-High vs. Low-Low Rating-NSFR Banks** - This table compares the characteristics of banks with high rating - high NSFR ($N = 22$) and low rating - low NSFR ($N = 35$) as of August 2007. The balance sheet categories are defined over total assets. The last column shows the value of the t-statistic for a test whether the difference in means between both groups is equal to zero.

	HH $N = 22$		LL $N = 35$		
	Mean	Std.dev.	Mean	Std.dev.	t-test
Panel A					
Assets	56,033	79,217	64,934	79,087	- 0.61
D. non-distressed sovereign	0.59	0.50	0.66	0.48	- 0.49
Panel B - Asset					
Cash and deposits CB ($w = 0$)	0.40	0.53	0.59	0.83	- 1.31
Government debt ($w = 0.05$)	6.03	7.83	3.22	3.39	1.83
MFI loans and corporate debt ($w = 0.15$)	21.41	18.09	16.71	10.34	0.94
Loans < 1y ($w = 0.5$)	13.63	10.19	12.71	9.34	0.40
Household mortgages > 1y ($w = 0.65$)	5.43	4.58	6.91	6.51	- 1.04
Household, NFC Loans > 1y & Equity ($w = 0.85$)	27.94	17.13	33.86	18.21	- 0.78
Other ($w = 1$)					
- MFI and other debt	7.71	9.06	11.02	11.35	-1.72
- MFI and other equity	1.36	2.05	1.65	2.94	- 0.26
- Loans to OFI	12.26	14.63	11.55	9.74	-0.22
- Other assets	3.84	4.43	5.90	8.74	-0.95
Panel C - Liability					
Debt < 1y, Repo and MFI dep. ($w = 0$)	22.11	14.11	43.88	14.24	-5.64
NFC overnight and govern. dep. ($w = 0.5$)	7.79	9.12	7.98	6.44	-0.08
NFC dep. > 3month ($w = 0.9$)	14.35	13.88	10.31	9.07	1.16
Households dep. < 1y ($w = 0.95$)	21.77	22.61	12.99	10.54	1.71
Other ($w = 1$)					
- Households dep. > 1y	0.52	0.99	1.52	2.73	-1.95
- NFC dep. > 1y	0.23	0.44	0.28	0.49	-0.38
- Debt > 1y	26.12	27.14	20.55	15.21	0.84
- Equity	6.16	4.07	6.96	6.29	-0.58

Table 6: **Model parameters**

Variable	**Symbol**	**HH**	**LL**	**Source**
Panel A				
Cash - Safe asset	W_0	1	1	IBSI
Asset portfolio	A_0	99	99	IBSI
Stable deposits	P_0^S	25	10	IBSI
Unstable deposits	P_0^U	43	62	IBSI
Debt	P_0^D	26	21	IBSI
Equity	E_0	6	7	IBSI
Panel B				
CB risk-free rate	r	1.25%		ECB
CB penalty spread	s^{CB}	0.50%		ECB
Loans' maturity (years)	δ	9.17	9.36	IBSI
Volatility of asset-shock	σ^X	8.99%	9.31%	IBSI
Risk premium	$\widetilde{\mu}^X$	3.3%	3.3%	Literature
Unit price for loan investment	ψ^+	4%	4%	Literature
Unit price for loan disinvestment	ψ^-	5%	5%	Literature
Unstable funding maturity (years)	m^U	0.19	0.25	IBSI & CSDB
Unstable funding spread	s^U	-0.25%	0.62%	IBSI & CSDB
Debt maturity (years)	m^D	3.46	3.46	CSDB
Debt coupon spread	s^D	0.36%	0.93%	CSDB
CB borrowing capacity	$1-\Theta$			IBSI & ECB haircuts
- Securities		15.25%	14.41%	
- Securities and loans		28.18%	33.51%	

Table 7: **Calibrated model parameters and moments -** The table summarises the calibrated model parameters and reports the mean (10th percentile, median and 90th percentile in brackets) for the historical default rate of the rating category, the dividends' payment frequency and the dividends' payment over equity, and the frequency of equity issuance and the equity amount issued over equity. Data sample IBSI-SNL: July 2007 - February 2015. Model panel data based on $50,000$ simulations. Note that the fixed cost of issuing equity ϕ and the marginal cost of issuing equity γ are identical across the two bank groups given the number of observations of equity issuance.

Parameter	**Value**	**Moment**	**Data**	**Model**
Panel A - HH				
		CB borrowing / assets (%)	1.52 [0 0 5.92]	1.68 [0 0 6.58]
l	64%	Historical default rate (%)	0.43	0.38
λ	1%	Dum. dividends* (%)	3.23	1.16
		Dividends / equity* (%)	3.27 [1.54 2.82 5.52]	0.89 [0.18 0.81 1.71]
ϕ	0.75	Dum. equity issuance (%)	1.44	0.07
γ	6%	Equity issuance / equity (%)	15.72 [2.16 9.11 31.28]	58.85 [49.31 57.89 70.45]
Panel B - LL				
		CB borrowing / assets (%)	2.93 [0 0 10.06]	3.79 [0 0 14.47]
l	72%	Historical default rate	0.49/3.32	2.09
λ	1%	Dum. dividends (%)	3.46	1.52
		Dividends / equity (%)	2.63 [0.96 1.81 5.52]	0.98 [0.21 0.77 1.99]
ϕ	0.75	Dum. equity issuance (%)	1.44	0.11
γ	6%	Equity issuance / equity (%)	15.72 [2.16 9.11 31.28]	60.83 [50.58 59.61 72.01]

Table 8: **CB borrowing capacity and penalty rate: CB borrowing, liquidation and investment -** Columns (1) and (3) report the mean of model panel data based on $50,000$ simulations with a $15-$year horizon (monthly frequency). Columns (2) and (4) are based on the model solution. Column (4) reports the investment over assets at (W_0, A_0).

		(1)	(2)	(3)	(4)
$1-\Theta$	s^{cb}	CB borrowing over assets (%)	Equity-liquid. hurdle (W^*, A^*)	Default frequency (%)	Investment over assets (%)
HH					
28.18%	0.5%	1.68	$(-18, 67)$	0.38	6.91
28.18%	0%	1.73	$(-18, 67)$	0.34	6.94
15.25%	0.5%	0.65	$(-10, 66)$	0.19	6.58
15.25%	0%	0.65	$(-10, 66)$	0.19	6.59
0%			$(0, 66)$	0.02	6.18
LL					
33.51%	0.5%	3.79	$(-24, 74)$	2.09	7.92
33.51%	0%	3.94	$(-24, 73)$	0.85	7.95
14.41%	0.5%	1.06	$(-10, 72)$	0.27	7.43
14.41%	0%	1.08	$(-10, 72)$	0.25	7.44
0%			$(0, 71)$	0.12	6.81

Table 9: **CB borrowing capacity and penalty rate: equity value, equity issuance and dividends' payment -** Columns $(2)-(4)$ report the mean of model panel data based on $50,000$ simulations with a $15-$year horizon (monthly frequency). Column (1) is based on the model solution and reports the equity value at (W_0, A_0).

		(1)	(2)	(3)	(4)
$1-\Theta$	s^{cb}	Equity value	Original ownership equity (%)	Dummy equity issuance (%)	Dummy dividends' payment (%)
HH					
28.18%	0.5%	87.70	97.33	0.070	1.166
28.18%	0%	88.36	97.34	0.071	1.299
15.25%	0.5%	82.37	95.40	0.120	0.478
15.25%	0%	82.48	95.52	0.117	0.479
0%		73.13	87.37	0.238	0.172
LL					
33.51%	0.5%	85.13	95.01	0.112	1.521
33.51%	0%	86.13	94.47	0.124	1.626
14.41%	0.5%	78.61	89.57	0.246	0.710
14.41%	0%	78.71	89.38	0.250	0.704
0%		71.64	80.41	0.426	0.376

8 Figures

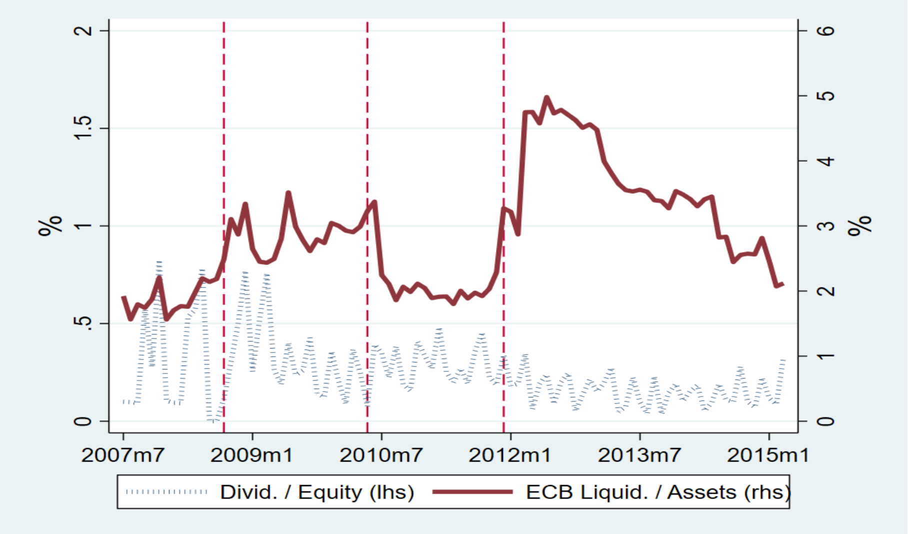

Figure 1: **Banks' dividends and ECB liquidity draws -** The figure plots the average dividends payout over equity (lhs) and the average liquidity drawn from the ECB over assets (rhs) for all the banks in our sample for the period 2007 to 2015. The first vertical line marks at September 2008 (Lehman Brothers), the second vertical line marks at April 2010 (Greek crisis) and the third vertical line marks at December 2011 (3−year LTROs).

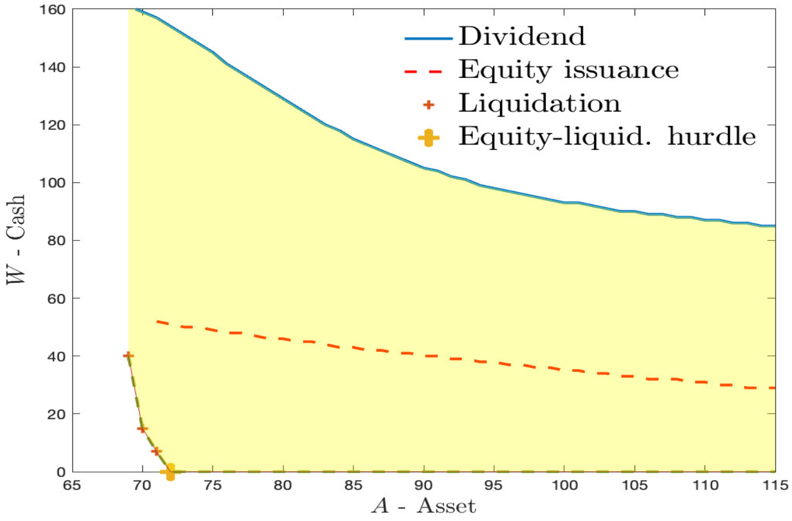

Figure 2: **Counterfactual solution -** This figure illustrates the optimal strategy for a bank who does not have access to CB liquidity. The yellow region corresponds to earnings retention region.

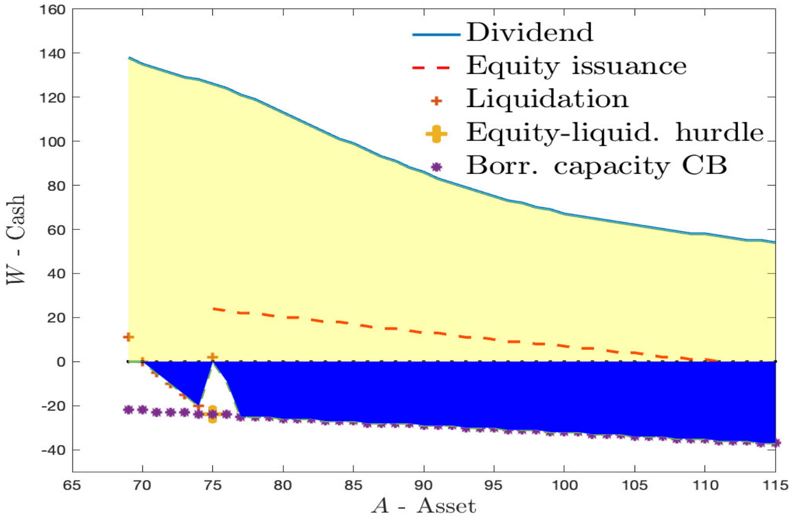

Figure 3: **CB solution -** This figure illustrates the optimal strategy for a bank who has access to CB liquidity. The yellow region corresponds to earnings retention region. The blue region corresponds to CB liquidity reliance region.

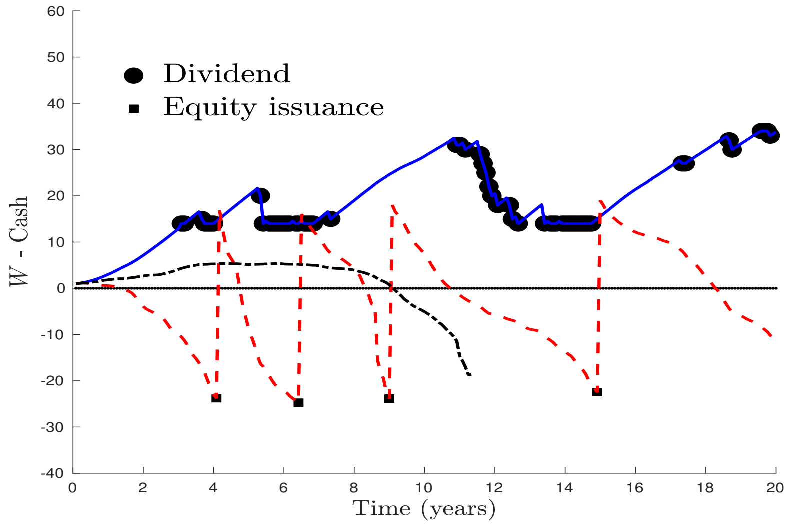

Figure 4: **Cash dynamics -** This figure illustrates the dynamics of the optimal policy for a bank who has access to CB liquidity. We show three possible scenarios for the cash W dynamics: i) equity issuance (dashed red line) and ■ indicates where the bank raises equity ii) dividend payment (continuous blue line) and • indicates where the dividends are paid; and iii) default (dashed-dotted black line).

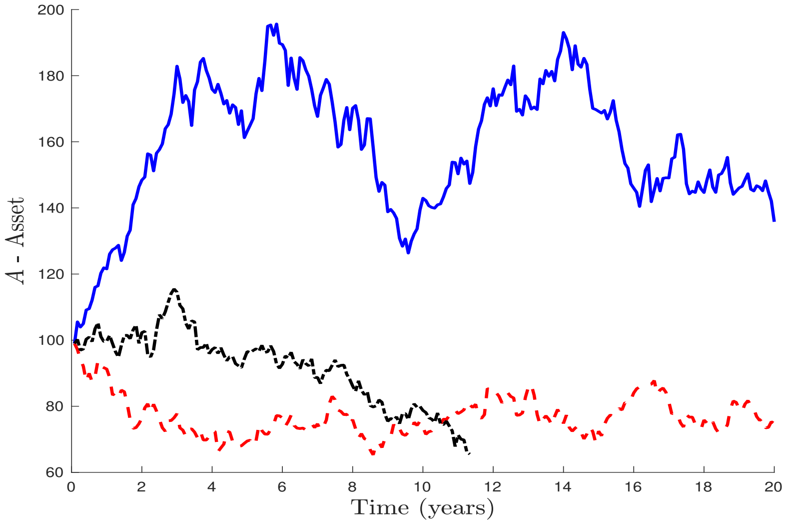

Figure 5: **Asset portfolio dynamics -** This figure illustrates the dynamics of the optimal policy for a bank who has access to CB liquidity. We show the three corresponding scenarios for the asset portfolio A dynamics: i) equity issuance (dashed red line) ii) dividend payment (continuous blue line); and iii) default (dashed-dotted black line).

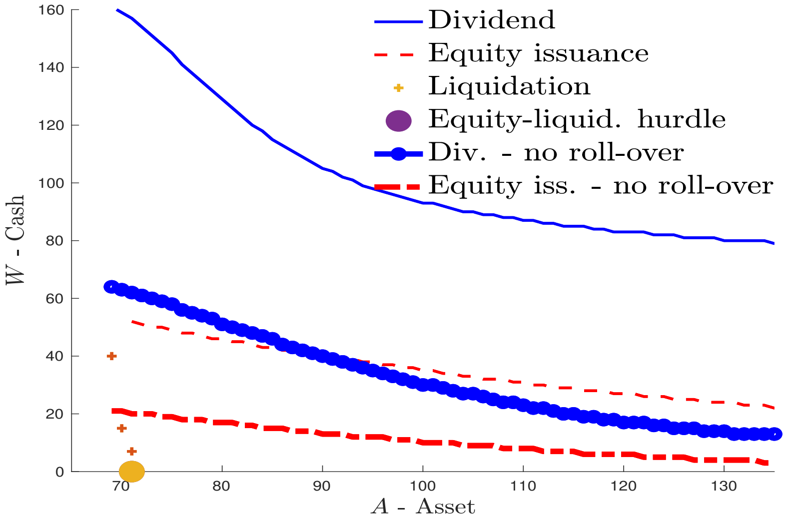

Figure 6: **Counterfactual with and without bank roll-over risk -** This figure illustrates the optimal strategy for a bank who does not have access to CB liquidity with and without roll-over risk.

References

Alves, Nuno, Diana Bonfim, and Carla Soares. 2021. "Surviving the perfect storm: The role of the lender of last resort." *Journal of Financial Intermediation* 47:100918.

Ashcraft, Adam, Nicolae Garleanu, and Lasse Heje Pedersen. 2011. "Two monetary tools: Interest rates and haircuts." *NBER Macroeconomics Annual* 25 (1): 143–180.

Asvanunt, Attakrit, Mark Broadie, and Suresh Sundaresan. 2011. "Managing corporate liquidity: Strategies and pricing implications." *International Journal of Theoretical and Applied Finance* 14 (03): 369–406.

Bai, Jennie, Arvind Krishnamurthy, and Charles-Henri Weymuller. 2018. "Measuring liquidity mismatch in the banking sector." *The Journal of Finance* 73 (1): 51–93.

Begenau, Juliane, Saki Bigio, Jeremy Majerovitz, and Matias Vieyra. 2020. "A q-theory of banks." Technical Report, National Bureau of Economic Research.

Bindseil, Ulrich, Marco Corsi, Benjamin Sahel, and Ad Visser. 2017. "The Eurosystem collateral framework explained." Technical Report, ECB Occasional Paper.

Bindseil, Ulrich, Kjell G Nyborg, and Ilya A Strebulaev. 2009. "Repo auctions and the market for liquidity." *Journal of Money, Credit and banking* 41 (7): 1391–1421.

Bocola, Luigi. 2016. "The pass-through of sovereign risk." *Journal of Political Economy* 124 (4): 879–926.

Bolton, Patrick, Hui Chen, and Neng Wang. 2011. "A unified theory of Tobin's q, corporate investment, financing, and risk management." *The Journal of Finance* 66 (5): 1545–1578.

Bolton, Patrick, Ye Li, Neng Wang, and Jinqiang Yang. 2021. "Dynamic banking and the value of deposits." Technical Report, National Bureau of Economic Research.

Bolton, Patrick, Neng Wang, and Jinqiang Yang. 2019. "Investment under uncertainty with financial constraints." *Journal of Economic Theory* 184:104912.

Carpinelli, Luisa, and Matteo Crosignani. 2021. “The design and transmission of central bank liquidity provisions.” *Journal of Financial Economics* 141 (1): 27–47.

Cassola, Nuno, Ali Hortaçsu, and Jakub Kastl. 2013. “The 2007 subprime market crisis through the lens of European central bank auctions for short-term funds.” *Econometrica* 81 (4): 1309–1345.

Corradin, Stefano, and Maria Rodriguez-Moreno. 2016. “Violating the law of one price: the role of non-conventional monetary policy.” *ECB Working Paper.*

Décamps, Jean-Paul, Thomas Mariotti, Jean-Charles Rochet, and Stéphane Villeneuve. 2011. “Free cash flow, issuance costs, and stock prices.” *The Journal of Finance* 66 (5): 1501–1544.

De Fiore, Fiorella, Marie Hoerova, and Harald Uhlig. 2017. “The Macroeconomic Impact of Money Market Freezes.” *2017 Meeting Papers.* Society for Economic Dynamics.

De Nicolo, Gianni, Andrea Gamba, and Marcella Lucchetta. 2014. “Microprudential regulation in a dynamic model of banking.” *The Review of Financial Studies* 27 (7): 2097–2138.

Drechsler, Itamar, Thomas Drechsel, David Marques-Ibanez, and Philipp Schnabl. 2016. “Who borrows from the lender of last resort?” *The Journal of Finance* 71 (5): 1933–1974.

Fahlenbrach, Rüdiger, Robert Prilmeier, and René M Stulz. 2012. “This time is the same: Using bank performance in 1998 to explain bank performance during the recent financial crisis.” *The Journal of Finance* 67 (6): 2139–2185.

———. 2018. “Why does fast loan growth predict poor performance for banks?” *The Review of Financial Studies* 31 (3): 1014–1063.

Fecht, Falko, Kjell G Nyborg, and Jörg Rocholl. 2011. “The price of liquidity: The effects of market conditions and bank characteristics.” *Journal of Financial Economics* 102 (2): 344–362.

Garleanu, Nicolae, and Lasse Heje Pedersen. 2011. “Margin-based asset pricing and deviations from the law of one price.” *The Review of Financial Studies* 24 (6): 1980–2022.

He, Zhiguo, and Wei Xiong. 2012a. “Dynamic debt runs.” *The Review of Financial Studies* 25 (6): 1799–1843.

———. 2012b. “Rollover risk and credit risk.” *The Journal of Finance* 67 (2): 391–430.

Hoerova, Marie, Caterina Mendicino, Kalin Nikolov, Glenn Schepens, and Skander Van den Heuvel. 2018. “Benefits and costs of liquidity regulation.” Technical Report, ECB Working Paper.

Hugonnier, Julien, and Erwan Morellec. 2017. “Bank capital, liquid reserves, and insolvency risk.” *Journal of Financial Economics* 125 (2): 266–285.

Jasova, Martina, Caterina Mendicino, and Dominik Supera. 2021. “Policy uncertainty, lender of last resort and the real economy.” *Journal of Monetary Economics* 118:381–398.

Leland, Hayne E. 1998. “Agency costs, risk management, and capital structure.” *The Journal of Finance* 53 (4): 1213–1243.

Leland, Hayne E, and Klaus Bjerre Toft. 1996. “Optimal capital structure, endogenous bankruptcy, and the term structure of credit spreads.” *The Journal of Finance* 51 (3): 987–1019.

Muthuraman, Kumar, and Sunil Kumar. 2008. “Solving free-boundary problems with applications in finance.” *Foundations and Trends in Stochastic Systems* 1 (4): 259–341.

Myers, Stewart C., and Nicholas S. Majluf. 1984. “Corporate financing and investment decisions when firms have information that investors do not have.” *Journal of Financial Economics* 13 (2): 187–221.

Nyborg, Kjell G. 2016. *Collateral frameworks: The open secret of central banks.* Cambridge University Press.

Reis, Ricardo. 2013. “The mystique surrounding the central bank’s balance sheet, applied to the European crisis.” *American Economic Review* 103 (3): 135–40.

Repullo, Rafael. 2005. “Liquidity, Risk Taking, and the Lender of Last Resort.” *International Journal of Central Banking*, pp. 47–80.

Stein, Jeremy C. 2013. “Lean, clean, and in-between.” *Speech given at the National Bureau of Economic Research Conference: Lessons from the Financial Crisis for Monetary Policy, Boston, October*, Volume 18.

Van Bekkum, Sjoerd, Marc Gabarro, and Rustom M Irani. 2017. “Does a larger menu increase appetite? Collateral eligibility and credit supply.” *The Review of Financial Studies* 31 (3): 943–979.

Woodford, Michael. 2010. “Comments on Ashcraft, Garleanu, and Pedersen,”Two monetary tools: interest rates and haircuts”.” *NBER Macroeconomics Annual* 25, no. 1.

A-I Online Appendix

A-I.1 Net Stable Funding Ratio (NSFR) computation

Required Stable Funding		**Available Stable Funding**	
Item	**Weights**	**Item**	**Weights**
Cash	0	Debt< 1y	0
Deposits at central banks	0	MFI deposits	0
Government debt	0.05	OFI deposits	0
MFI loans	0.15	CCP repo	0
Corporate debt	0.15	Other liabilities	0
Government loans	0.5	NFC deposits - overnight	0.5
Household loans < 1y	0.5	Government deposits	0.5
Household mortgages < 1y	0.5	NFC deposits > 3m	0.9
NFC loans < 1y	0.5	NFC deposits redeemable at notice	0.9
Household mortgages < 5y	0.65	NFC deposits at agreed maturity < 1y	0.9
Household mortgages > 5y	0.65	Household deposits - overnight	0.9
Household loans < 5y	0.85	Household deposits at agreed maturity < 1y	0.95
Household loans > 5y	0.85	Household deposits redeemable at notice	0.95
NFC loans < 5y	0.85	Household deposits row	0.95
NFC loans > 5y	0.85		
Other equity securities	0.85	Capital	1
MFI debt	1	Debt> 1y	1
MFI equity	1	Debt> 2y	1
Equity securities row	1	Household deposits at agreed maturity > 1y	1
Loans row	1	Household deposits at agreed maturity > 2y	1
Debt securities row	1	NFC deposits at agreed maturity > 1y	1
Loans to OFI	1	NFC deposits at agreed maturity > 2y	1
Other assets	1		
NSFR = ASF / RSF			

Figure A-I: **NSFR proxy** This table shows the variables NSFR proxy. We use MFI level IBSI data for 197 euro area banks to calculate a monthly NSFR proxy for each Monetary Financial Institution (MFI). The NSFR is defined as the ratio of Available Stable Funding over Required Stable Funding. NFC is short for non-financial corporation, OFI stands for other financial institution.

A-I.2 Measuring borrowing capacity with ECB in the euro area banking sector

We distinguish between two asset types: i) marketable assets and ii) non-marketable assets.

For marketable assets, we use data on security-level portfolio holdings of euro-area investors from the Securities Holding Statistics (SHS). The data are collected on a quarterly basis in the euro area since first quarter of 2009. Securities in our sample are identified by a unique International Securities Identification Number (ISIN). Investors in the SHS are defined by sector and by country of domicile. There are six aggregate sectors: households, monetary and financial institutions (MFI), insurance companies and pension funds (ICPF), other financial institutions (OFI), general government, and non-financial corporations. We refer to MFI as banks. The assets we cover include both government and corporate debt, asset-backed securities (ABS), and covered bonds providing a unique overview of the portfolios of banks in the euro area.

First, we merge the SHS data with data on the eligible securities published by the ECB at the end of each quarter. We verify whether an ISIN in SHS data is eligible for ECB liquidity operations and the haircut applied by the ECB if the security is eligible. Then, we link the SHS data to IBSI to compute aggregate ECB eligibility and haircut measures for the main IBSI asset balance sheet items (e.g. domestic sovereign investment) at bank level on a monthly frequency. The IBSI balance sheet item of an asset is determined by the combination of issuer sector (e.g. Government) and issuer area (e.g. Italy).

For the eligibility we compute an eligibility share for each issuer sector and issuer area combination

$$\text{Eligible}_{hc,is,ia,t} = \frac{\text{Tot. Market value eligible securities}_{hc,is,ia,t}}{\text{Tot. Market value securities}_{hc,is,ia,t}}$$

where hc is the banking sector holder of each euro-area country (e.g. Italian banks), is is the issuer sector, ia is the issuer area and t is the quarter.

For the haircuts we compute an average weighted ECB haircut for the eligible securities as

$$\theta_{hc,is,ia,t} = \sum_i \omega_{i,hc,is,ia,t} \times \tilde{\theta}_{i,t}$$

where $\tilde{\theta}_{i,t}$ is the ECB haircut for the eligible security i at quarter t that belongs to the categories is (issuer sector) and ia (issuer area). $\omega_{hc,is,ia,t}$ is a weight

$$\omega_{i,hc,is,ia,t} = \frac{\text{Market value of eligible security } i_{i,hc,is,ia,t}}{\text{Tot. Market value eligible securities}_{hc,is,ia,t}}$$

where Market value of eligible security $i_{i,hc,is,ia,t}$ is the market value of the security i held by the banking sector hc at time t. Figure A-II plots the average weighted ECB haircut $\theta_{hc,is,ia,t}$ for the Italian banking sector over the $2010q1$ to $2018q2$ sample period. The top panel plots the average weighted ECB haircut for bonds issued by Italian (or Domestic) Government, Banks and non-Banks. The bottom panel plots the average weighted ECB haircut for bonds issued by other euro area Government, Banks and non-Banks. The increase in haircuts we observe for Italian sovereign bonds (top panel) in the last part of the sample is due to the downgrade of Italian rating by the Canadian DRBS rating agency at the end of 2016. Before the downgrade, DBRS had Italy on an A low rating and was the only one of the major four credit agencies (including Standard&Poor's, Moody's and Fitch). The rating downgrade triggered an increase in ECB haircuts meaning Italian banking sector was subject to the highest haircut when posting government bonds as collateral with the central bank. According to our measure, the average haircut for Italian bonds held by the Italian banking sector rose from 2% to 8.6%. Overall Figure A-II provides evidence of substantial time-variation in the ECB haircuts that the euro-area banking sector can experience.

The overall ECB haircut is defined as

$$\Theta_{hc,is,ia,t} = \text{Eligible}_{hc,is,ia,t} \times \theta_{hc,is,ia,t} + (1 - \text{Eligible}_{hc,is,ia,t}) \times 100\%$$

applying a 100% haircut for the non-eligible share.

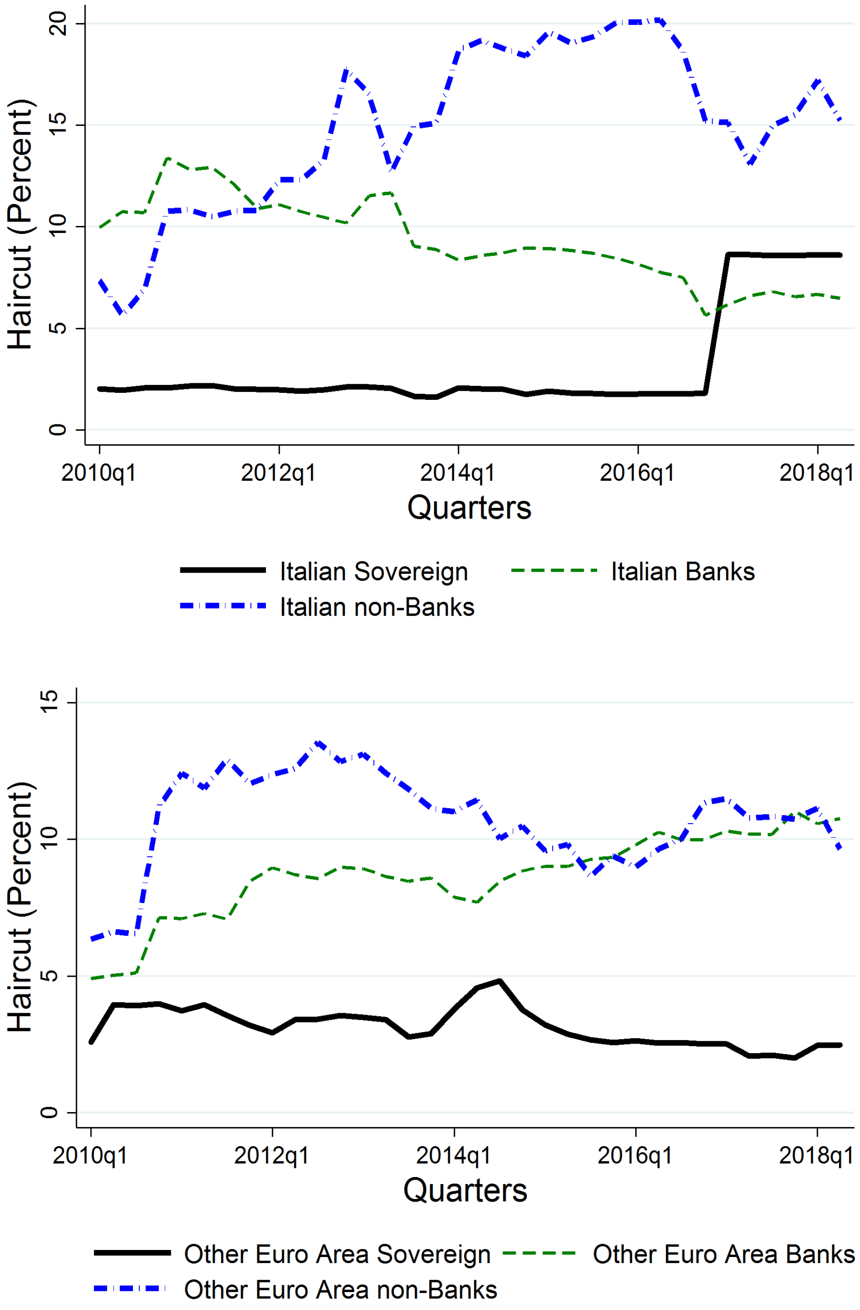

Figure A-II: ECB haircut for the Italian Banking Sector - $\theta_{hc,is,ia,t}$

Table A-I provides summary statistics of the eligibility and haircut measures for the euro area banking sector for the main IBSI categories of debt securities. Sovereign bonds are classified in three sub-categories: i) domestic; ii) other euro area (non-domestic); and iii) extra euro area. The same applies for securities issued by non-MFIs (e.g. corporate sector) and MFIs. Columns (1)-(3) provides the mean, the 10^{th} and 90^{th} percentile of the fraction of eligible marketable securities for each asset category. Columns (4)-(6) provides the mean, the 10^{th} and 90^{th} percentile of the aggregate haircut of eligible marketable debt securities for each asset category. As expected, the euro area sovereign bonds category has the largest ECB eligibility share and implied lower ECB haircut. When the issuer is non-sovereign (MFI and non-MFI), the eligibility share substantially decreases in particular for debt securities issued by non-MFIs and the implied ECB haircut significantly increases.

Table A-I: ECB Eligibility and Haircuts (numbers in %) - SHS data $2009-2016$

IBSI categories	ECB Eligible Share			ECB Haircut Θ		
Issuer	Mean	P10	P90	Mean	P10	P90
Sovereign						
Domestic	97.86	94.19	100.00	2.80	1.81	3.25
Other Euro Area	94.69	90.15	99.57	3.41	2.10	4.66
Extra Euro Area	28.29	3.53	51.32	3.79	2.29	5.67
MFI (Banks)						
Domestic	74.10	47.20	90.82	8.16	5.26	11.86
Other Euro Area	72.04	50.61	87.83	8.13	5.84	10.85
Extra Euro Area	50.05	26.09	75.62	6.49	4.48	8.40
Non MFI						
Domestic	56.37	16.13	80.65	10.61	5.11	21.30
Other Euro Area	68.32	46.19	83.81	9.30	5.55	13.68
Extra Euro Area	27.13	9.96	38.82	9.90	5.12	17.90

Finally, we merge our ECB eligibility and haircut dataset with IBSI at country level and monthly frequency. The borrowing capacity with ECB of bank j belonging to MFI country sector hc for a specific marketable asset category $is-ia$ (issuer sector-issuer area) at quarter t is defined as

$$\widetilde{MA}_{j,is,ia,t} = (1-\Theta_{hc,is,ia,t}) \times MA_{j,is,ia,t},$$

where $MA_{j,is,ia,t}$ is the market value of the marketable asset category $is-ia$ reported in IBSI at time t. This measure has to be interpreted as the maximum amount that the bank j can borrow from ECB pledging all the securities of the category $is-ia$ at time t. The measure can be netted by the actual pledging of securities of the category $is-ia$ to the ECB. However, the measure does not account for encumbered securities in private repo and security lending transactions due to lack of data. The measure $\widetilde{MA}_{j,is,ia,t}$ can be aggregated across issuer sector is and issuer area ia to compute an overall borrowing capacity of the marketable assets for the bank j at time t

$$\widetilde{MA}_{j,t} = \sum_{is} \sum_{ia} \widetilde{MA}_{j,is,ia,t}.$$

For non-marketable assets, we rely on the ECB eligibility criteria taking into account when eligibility criteria and haircuts were revised. Four types of non-marketable assets are currently eligible as collateral: i) fixed-term deposits from eligible counterparties, ii) credit claims, iii) non-marketable retail mortgage-backed debt instruments (RMBDs) and iv) additional credit claims. Eligible credit claims are bank loans issued by the public sector, non-financial corporations, international and supranational institutions in the euro area.[1] The scope for accepting eligible credit claims has furthermore been expanded by the additional credit claims (ACC) framework that was implemented in December 2011 as a temporary measure whereby other types of credit claims, such as residential mortgages or pools of credit claims, became eligible in certain euro area jurisdictions under additional specific criteria.

The use of credit claims as collateral is generally perceived by counterparties costly compared with marketable assets. This stems from the legal requirements for mobilisation or transfer set by national legislations, the relatively limited availability of credit ratings for the debtors in some jurisdictions, operational requirements imposed by collateral takers (e.g. central banks) and/or relatively less automated procedures for collateralization compared with those for marketable assets. The relatively high operational costs of the use of credit claims as collateral can also be seen in the additional eligibility and operational requirements for credit claims that are not required for marketable assets by the ECB. The requirements relate to: (i) ex ante notification of the debtor about mobilisation (in some jurisdictions); (ii) physical delivery of related loan documents; (iii) transferability of credit claims; and (iv) reporting requirement of counterparties regarding the existence of credit claims.

We identify eligible IBSI loan items for each bank looking at the issuer (public sector, non-

---

[1] Syndicated loans are also in principle accepted as collateral, but their use so far has been limited.

financial corporations (non-MFIs), international and supranational institutions), the place of establishment (euro area) and the currency (euro). Due to lack of data on the amount of loans issued by each bank j eligible for ECB liquidity operations, we assume that all the loans belonging to a specific eligible category $is - ia$ (issuer sector - issuer area) are eligible. Finally, to measure the borrowing capacity for each bank j we use the ECB haircuts applied to the category $is - ia$. ECB haircuts depend on the credit quality and time-to-maturity of the eligible loans. Due to lack of data we have to apply an average ECB haircut. Thus, the borrowing capacity of bank j belonging to MFI country sector hc for a specific non-marketable asset category $is - ia$ (issuer sector-issuer area) at quarter t is defined as

$$\widetilde{NMA}_{j,is,ia,t} = (1 - \Theta_{is,ia,t}) \times NMA_{j,is,ia,t},$$

where $NMA_{j,is,ia,t}$ is the value of the non-marketable asset category $is - ia$ reported in IBSI at time t. Our measure for non-marketable assets has to be interpreted as the maximum amount that the bank j can borrow from ECB pledging loans of the eligible category $is - ia$ at time t. The measure $\widetilde{MA}_{j,is,ia,t}$ can be aggregated across issuer sector is and issuer area ia to compute an overall borrowing capacity of the marketable assets for the bank j at time t

$$\widetilde{NMA}_{j,t} = \sum_{is} \sum_{ia} \widetilde{NMA}_{j,is,ia,t}.$$

Figure 2 plots the mean, the 10^{th} and 90^{th} percentiles of $\widetilde{NMA}_{j,t}$ over the total amount of loans of bank j. We observe a large but stable cross sectional dispersion with a mean of 33%.

A-I.3 Calibration: Asset volatility

To estimate σ_X, we use a panel regression. We infer the parameters using the following relation:

$$\begin{aligned} A_t dX_t + dA_t &= \mu^X A_t dt + \sigma^X A_t dZ_t + \left(-\frac{1}{\delta} A_t + I^* \right) dt \\ &= \left(\mu^X - \frac{1}{\delta} \right) A_t + I^* + \sigma^X A_t dZ_t \end{aligned} \tag{A-1}$$

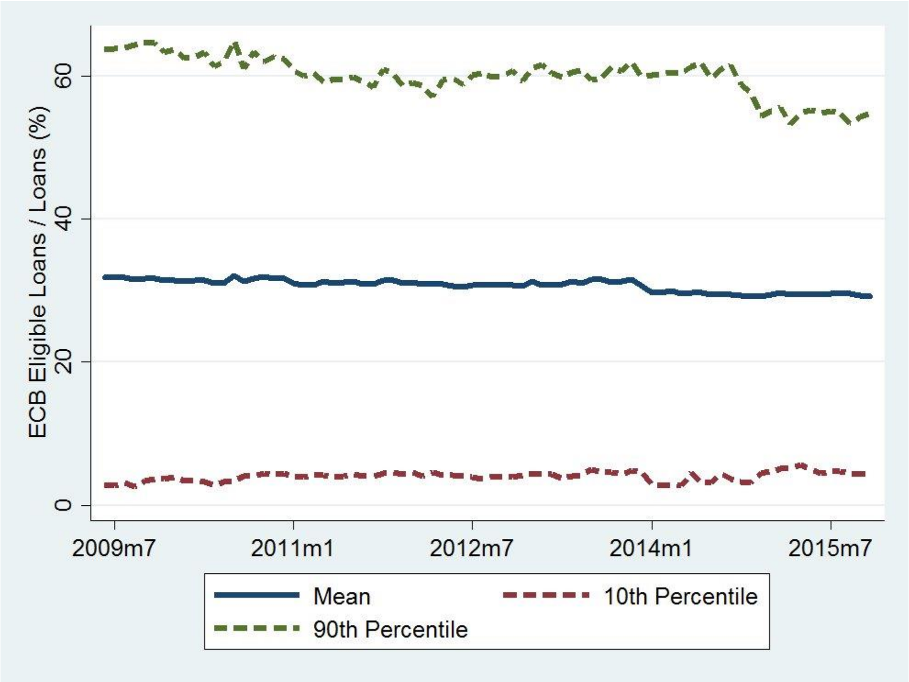

Figure A-III: Non-marketable assets (loans) - $\widetilde{NMA}_{j,t}$/Total Loans$_{j,t}$

where the first component is the market loss/gain cash over the time interval dt. We can rescale the relation over A_t. Then, we estimate the following panel regression on the asset growth rate of household and non-financial corporations (NFC) loans over the period July 2007 - April 2010 (monthly frequency)

$$\frac{\Delta A_{i,t}}{A_{i,t}} = \gamma_i + \phi_t + \beta \times \frac{\mathrm{I}_{i,t}}{A_{i,t}} + \epsilon_{i,t} \tag{A-2}$$

where γ_i is a bank fixed-effect, ϕ_t is a time fixed-effect, and I is the monthly investment on household and NFC loans. The variable I includes new business (no disinvestment). σ^X is estimated via the residual $\epsilon_{i,t}$.

A-I.4 Model

From a modeling perspective, our approach draws from the insights of Bolton, Chen, and Wang (2011), Hugonnier and Morellec (2017), and Décamps et al. (2011). For brevity, we just focus on Bolton, Chen, and Wang (2011) who provide a framework wherein a firm can alter optimally its investment policy and will also have the ability to manage its liquidity through both cash balances and lines of credit. By modeling both the asset side and the liability side, they come close to the ideas developed in our paper. In their framework, the key variable is the ratio of cash to capital, which effectively serves as the single, key state variable. They get a "double barrier" characterization of liquidity management in which their key state variable plays an important role. In our formulation, both the loan portfolio size and the amount of cash buffer both enter as state variables, and the problem cannot be collapsed into a single state variable as in Bolton, Chen, and Wang (2011), due to the richer structure of the economy studied in the paper. Our model allows for private debt in addition to adjustments on the asset side of the balance sheet. In addition, in our model the Central Bank is explicitly considered. With the presence of private debt in our model, accessing Central Bank liquidity is a nuanced decision for the bank - we model this explicitly. First, we allow the banks to be closed by resolution authorities when the bank capital falls below a certain threshold. In this sense, the closure policies of the regulators inform on the decisions of banks to draw on central bank liquidity. Second, banks perform maturity transformation: a fraction of their debt matures each instant, whereas the assets have a larger average life. These are important dimensions on which our theoretical framework differs from the work of Bolton, Chen, and Wang (2011). In a related paper Bolton et al. (2021) offer a Q-theory of deposits where banks may not have control over their deposit levels. It addresses how uncertainty about deposit levels can lead to a reexamination of capital regulation. Begenau et al. (2020) develop a dynamic theory of banking with a focus on leverage dynamics when loan losses are recognized with a delay and banks are subject to regulatory capital requirements. The work by De Nicolo, Gamba, and Lucchetta (2014) is also closely related to our work. They provide a dynamic model of banking in which the banks transform short-dated insured deposits into long-dated loans, and are subject to regulation. The banks in their model are also subject to default risk due to costly external equity issuance and inability to issue un-collateralised debt, leaving a clear role for regulation of banks. They use their framework to link capital requirements and liquidity requirements on banks' optimal decisions. He and Xiong (2012b) model the role of short-term debt in the amplification of rollover risk. They apply the model to corporate debt, default, and liquidity premia. In a companion paper, He and Xiong (2012a) model the dynamic coordination problem when multiple creditors have rollover decisions to make.

A-I.4.1 Solution: Equity valuation

Equity value depends on two state variables, its stock of cash W and its assets' portfolio A. Let $E(W, A)$ denote equity value. When $W_t > 0$ the bank is in the "cash region", i.e., the bank is carrying positive cash buffer. When $W_t \leq 0$, the bank is in the "credit region", i.e., it is drawing liquidity from the CB liquidity facility.

In the CB model, we consider six regions: i) a payout region where the bank distributes dividends to shareholders; ii) internal financing region where the bank holds cash; iii) CB funding region where the bank relies on CB liquidity; iv) a refinancing region where equity holders are willing to issue equity and v) a liquidation region where equity holder prefer liquidation instead of issuing equity and vi) default when the asset value is below the exogenously specified level, representing the minimum total capital requirements.

The bank chooses its investment I, payout policy U and external financing policy H to maximise shareholder value subject to i) the asset portfolio equations (4), ii) the cash equations (9) and (10), and iii) the boundary conditions (11) and (12):

$$\max_{I,U,H} \mathrm{E}\left[\int_0^{\tau} e^{-rt}\left(dU_t - dH_t - \Phi(dH_t)\right) + e^{-r\tau}\max(W_\tau + l \times A_\tau - P^D - P^U - P^S, 0)\mathbb{1}_{\tau=\min(\tau_l,\tau_d)}\right]. \tag{A-3}$$

The first term is the discounted value of net payouts to shareholders where U_t denotes cumulative dividends and H_t denotes the cumulative costs of external financing up to time t, and $\Phi(dH_t)$ denotes the incremental costs of raising incremental external funds dH_t. The second term is the discounted value from liquidation. The liquidation occurs in two circumstances: i) default triggered by regulatory authorities $\tau = \tau_d$; or ii) when equity holders prefer liquidation instead of issuing equity $\tau = \tau_l$. Note that equity issuance is costly and can hurt the value of existing equity holders. We consider below the different regions.

1. **Payout Region $\overline{W}(A) < W$**

   When the cash position is very high, the bank is better off paying out the excess cash to shareholders to avoid the cash-carrying cost. The natural question is how high the cash-loan ratio needs to be before the bank pays out. Let $\overline{W}(A)$ denote this endogenous payout boundary. Intuitively, if the bank starts with a large amount of cash, then it is optimal for the bank to distribute the excess cash as a lump sum and bring the cash-loan ratio $W(A)$ down to $\overline{W}(A)$. Moreover, bank's equity value must be continuous before and after cash distribution. Therefore, for $W(A) > \overline{W}(A)$, we have the following equation for $E(W, A)$:

$$E(W, A) = \underbrace{\left(W(A) - \overline{W}(A)\right)}_{\text{Cash distribution}} + E(\overline{W}(A), A) \quad \text{if} \quad W(A) > \overline{W}(A). \tag{A-4}$$

Since the above equation also holds for $W(A)$ close to $\overline{W}(A)$, we may take the limit and obtain the following condition for the endogenous upper boundary:

$$E_W(\overline{W}(A), A) = 1. \tag{A-5}$$

2. **Internal Financing Region $\overline{W}(A) > W \geq 0$**

   The partial differential equation (PDE) for the equity value $E(W, A)$ is

$$\begin{aligned} rE = &\left((r-\lambda)W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D}(D(W, A, m^D; s^D) - P^D)\right. \\ &\left. - C^U + \frac{1}{m^U}(D(W, A, m^U; s^U) - P^U)\right) E_W \\ &+ \left((r + \widetilde{\mu}^X)A + I^* - \frac{A}{\delta}\right) E_A + \frac{(\sigma^X A)^2}{2} E_{AA}, \end{aligned} \tag{A-6}$$

   where the investment then satisfies the following first-order condition:

$$I_t = \frac{1}{2(\psi^+ \mathbb{1}_{I_t \geq 0} + \psi^- \mathbb{1}_{I_t < 0})} \left(\frac{E_W(W, A)}{E_A(W, A)} - 1\right) \tag{A-7}$$

   and $E_W(W, A)$ and $E_A(W, A)$ is the marginal value of equity with respect to cash and asset portfolio respectively.

3. **CB Funding Region $\underline{W}(A) \leq W < 0$**

The PDE for the equity value $E(W, A)$ is

$$\begin{aligned} rE = &\Bigg((r + s^{CB})W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D}(D(W, A, m^D; s^D) - P^D) \\ &-C^U + \frac{1}{m^U}(D(W, A, m^U; s^U) - P^U)\Bigg) E_W \\ &+ \left((r + \widetilde{\mu}^X)A + I^* - \frac{A}{\delta}\right) E_A + \frac{(\sigma^X A)^2}{2} E_{AA}, \end{aligned} \tag{A-8}$$

where s^{CB} is the constant CB spread over the risk-free rate r on the amount of credit the bank uses. The investment policy still satisfies the first-order condition (A-7).

4. **Refinancing**

Because of the fixed costs of financing, the bank only considers raising equity when cash flow shocks deplete its liquid reserves. In such instances, the bank has to either raise new funds to continue operating or liquidate (see point 5). The bank chooses to liquidate when the cost of refinancing or the liquidation value of risky assets are large. When liquidation is not optimal the bank incurs a fixed cost ϕ and a cost γ proportional to the amount of equity raised. Bank's equity value is continuous before and after equity issuance which implies the following condition

$$E(\underline{W}(A), A) = E(\widetilde{W}(A), A) - \underbrace{\phi}_{\text{Fixed cost}} - (1 + \underbrace{\gamma}_{\text{Marginal cost}}) \times (\widetilde{W}(A) - \underline{W}(A)), \tag{A-9}$$

where $\widetilde{W}(A) - \underline{W}(A)$ is the equity issuance amount. We refer to $\widetilde{W}(A)$ as the cash return point after equity issuance. This gives the following smooth pasting boundary condition:

$$E_W(\widetilde{W}(A), A) = 1 + \gamma. \tag{A-10}$$

In the counterfactual, the bank raises equity when it runs out cash ($\underline{W}(A) = 0$)

$$E(0, A) = E(\widetilde{W}(A), A) - \underbrace{\phi}_{\text{Fixed cost}} - (1 + \underbrace{\gamma}_{\text{Marginal cost}}) \times \widetilde{W}(A).$$

5. **Liquidation**

   The payoff shareholders receive if they liquidate the bank is

$$E(\underline{W}(A), A) = \max(\underline{W}(A) + l \times A - P^D - P^U - P^S, 0), \tag{A-11}$$

   incurring in additional dead-weight losses denoted by the fraction l. If $(A-11) > A-9$ it is never optimal for shareholders to refinance and the bank is liquidated the first time that cash reaches $\underline{W}(A)$. We denote with τ_l the stochastic liquidation time. Therefore, we need to identify the abandonment hurdle $A^*(W)$ at which equity holders are just indifferent between abandoning the bank or not.

6. **Insolvency - banks violating minimum capital requirements** We assume that the bank's bankruptcy is triggered when

$$A^B = l \times A_0 \tag{A-12}$$

   where A_0 denotes the asset portfolio value at time 0. We denote with τ_d the stochastic insolvency time. The payoff shareholders receive is

$$E(W, A) = \max(W + l \times A - P^D - P^U - P^S, W) \qquad \text{if} \quad A \leq A^B. \tag{A-13}$$

   As in Asvanunt, Broadie, and Sundaresan (2011) we assume that the bank anticipates bankruptcy and passes the cash to shareholders so that debt holders will not receive it upon liquidation.

A-I.4.2 Solution: Debt valuation

Analogous to equity valuation in different regions described in the previous section, the debt value $D(W, A, m^D; s^D)$ behaves as follows in different regions.

1. **Payout Region** $\overline{W}(A) < W$

When $W(A) = \overline{W}(A)$, we have the following condition for $D(W, A, m^D; s^D)$:

$$D_W(W, A, m^D; s^D) = 0. \tag{A-14}$$

This condition follows from the fact that the expected life of the bank does not change as W approaches $\overline{W}(A)$ since $\overline{W}(A)$ is a reflective barrier.

2. **Internal Financing Region** $\overline{W}(A) > W \geq 0$

   The PDE for the debt value $D(W, A, m^D; s^D)$ is

$$\begin{aligned}\left(r + \frac{1}{m^D}\right) D = {} & C^D + \frac{1}{m^D} \times P^D \\ & + \left((r-\lambda)W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D}(D(W, A, m^D; s^D) - P^D)\right. \\ & \left. -C^U + \frac{1}{m^U}(D(W, A, m^U; s^U) - P^U)\right) D_W \\ & + \left((r + \widetilde{\mu}^X)A + I^* - \frac{A}{\delta}\right) D_A + \frac{(\sigma^X A)^2}{2} D_{AA},\end{aligned} \tag{A-15}$$

   where $C^D + \frac{1}{m^D} \times P^D$ is the constant payment rate.

3. **CB Funding Region** $\underline{W}(A) \leq W < 0$

   The PDE for the debt value $D(W, A)$ is

$$\begin{aligned}\left(r + \frac{1}{m^D}\right) D = {} & C^D + \frac{1}{m^D} \times P^D \\ & + \left((r + s^{CB})W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D}(D(W, A, m^D; s^D) - P^D)\right. \\ & \left. -C^U + \frac{1}{m^U}(D(W, A, m^U; s^U) - P^U)\right) D_W \\ & + \left((r + \widetilde{\mu}^X)A + I^* - \frac{A}{\delta}\right) D_A + \frac{(\sigma^X A)^2}{2} D_{AA}.\end{aligned} \tag{A-16}$$

4. **Refinancing**

   Debt value is continuous before and after equity issuance which implies the following condition

$$D(\underline{W}(A), A, m^D; s^D) = D(\widetilde{W}(A), A, m^D; s^D). \tag{A-17}$$

5. **Liquidation**

The payoff bondholders receive if shareholders liquidate the bank is

$$D(\underline{W}(A), A, m^D; s^D) = \min(\max(l \times A \times (1 - \Theta) - P^S, 0), P^D). \tag{A-18}$$

Condition (A-18) follows from the priority rule which states that debt payments have to be serviced in full to the CB accounting for the collateral pledge before bond holders collect any liquidation proceeds.

For our calibration exercise (see Section 5.1) we consider two types of debt securities that are exposed to rollover risk: i) secured debt with a time-to-maturity above one year with a principal P^D; and ii) unstable wholesale funding associated with a $0, 0.5$ and 0.9 weight in the NSFR ratio and the overnight households deposits with a principal P^U. The latter type of debt is junior with a lower priority than CB liquidity and secured debt. Therefore, the payoff for these bondholders if shareholders liquidate the bank is

$$M(\underline{W}(A), A, m^U; s^U) = \min(\max(l \times A + \min(\underline{W}(A), 0) - P^S - P^D, 0), P^U). \tag{A-19}$$

6. **Insolvency**

When the bank's bankruptcy is triggered the payoff bondholders receive is

$$D(W, A, m^D; s^D) = \min(\max(l \times A \times (1 - \Theta) - P^S, 0), P^D) \qquad \text{if} \quad A \leq A^B. \tag{A-20}$$

Similarly, the payoff of the unstable wholesale funding is

$$M(\underline{W}(A), A, m^U; s^U) = \min(\max(l \times A + \min(\underline{W}(A), 0) - P^S - P^D, 0), P^U) \qquad \text{if} \quad A \leq A^B. \tag{A-21}$$

A-I.4.3 Numerical approach

We adopt an iterative two-step procedure for a sequence of fixed boundary problems (Muthuraman and Kumar (2008)). We begin the iterative procedure with an initial choice for the region of inaction $B^{\{i,j\}}$ where i denotes the second step while j denotes the first one. We rely on an implicit solution approach involving a finite difference approximation of the PDEs (A-6), (A-8), (A-15) and (A-16) to find the value functions in the inaction region $B^{\{i,j\}}$. Then, we iterate to obtain successive regions of inaction $B^{\{1,1\}}, B^{\{1,2\}}, ..., B^{\{2,1\}}, B^{\{2,2\}}...$ and the corresponding value functions for the equity value $E^{\{1,1\}}, E^{\{1,2\}}, ..., E^{\{2,1\}}, E^{\{2,2\}}...$ and the debt value $D^{\{1,1\}}, D^{\{1,2\}}, ..., D^{\{2,1\}}, D^{\{2,2\}}...$.

In our problem, the equity market value $E(W, A)$ depends on the debt and unsecured deposits market values $D(W, A, m^D; s^D)$ and $M(W, A, m^U; s^U)$. To initialise our numerical procedure, we use the solution of the first best case where the bank can issue equity at no cost as a first "good" guess for the equity value and the investment policy. The debt and unsecured deposits market values $D(W, A, m^D; s^D)$ and $M(W, A, m^U; s^U)$ are set at the risk-free value. If the asset value $A \leq A^B$ the equity and debt values are set at their liquidation value.

We begin by choosing an arbitrary region of inaction $B^{\{0,0\}}$ as $(\overline{W}^{\{0,0\}}(A), \underline{W}^{\{0,0\}}(A))$ in the first iteration. The arbitrary region has to be larger than the optimal region of inaction, but the cash boundary $\underline{W}^{\{0,0\}}(A)$ is delimited by the exogenous CB borrowing capacity $-(1-\Theta) \times A$. We also assume that shareholders only raise one unit of equity ΔW for any level of the asset A. With that in mind, we impose two desiderata on the update procedure:

1. **Inaction region -** We can summarise this step as follows:

   (a) We calculate the associated value function for the equity value $E^{\{0,1\}}(W, A)$ with the boundary conditions given $D^{\{0,0\}}(W, A, m^D; s^D)$ and $M^{\{0,0\}}(W, A, m^U; s^U)$ and the associated investment policy $I^{\{0,1\}}(W, A)$ using the first order condition (A-7).

   (b) We identify the endogenous hurdle $\underline{A}^*(W)$ verifying whether the equity value $E^{\{0,1\}}(\underline{W}^{\{0,1\}}(A), A)$ is negative for values of A close to A^B. In the first iteration, we "guess" that equity holders prefer issuing equity to liquidating the bank for any level of A implying that $\underline{A}^*(W) = A^B$. If $E^{\{0,1\}}(\underline{W}^{\{0,1\}}(A), A) < 0$, we increase $\underline{A}^*(W)$ by an increment ΔA and we repeat steps (a), (b), (c), (d) and (e) as far as $E^{\{0,j\}}(\underline{W}^{\{0,j\}}(A), A) \geq 0$ for any value of A.

(c) We update the dividend boundary $\overline{W}^{\{0,1\}}(A)$ relying on the following argument. Because the likelihood of costly refinancing or inefficient liquidation decreases as cash increases, we expect the marginal equity value of cash to be above one

$$E_W(W, A) \geq 1. \tag{A-22}$$

For high values of W (and for each value of A) we verify where $E_W(W, A) < 1$. If (A-22) is violated, we need to move the dividend boundary from $\overline{W}^{\{0,0\}}(A)$ to $\overline{W}^{\{0,1\}}(A)$ where $\overline{W}^{\{0,0\}}(A) > \overline{W}^{\{0,1\}}(A)$ such that $E_W^{\{0,1\}}(\overline{W}^{\{0,1\}}(A), A)$ is the minimum of $E_W^{\{0,1\}}$. Thus, we impose the condition

$$E_W^{\{0,1\}}(\overline{W}^{\{0,1\}}(A), A) = 1 \tag{A-23}$$

as a reflecting boundary condition at $\overline{W}^{\{0,1\}}(A)$: the shareholders are indifferent between holding cash and distributing dividends. In further iterations, we verify whether $E_W^{\{i,j\}}(W, A) > 1$ and $E_{WW}^{\{i,j\}}(W, A) \leq 0$ in the proximity of $\overline{W}^{\{i,j\}}(A)$. If the latter conditions fail, then it indicates that the arbitrarily chosen inaction region is not large enough and we therefore increase the $\overline{W}^{\{i,j\}}(A)$ by ΔW.

(d) We update the cash boundary $\underline{W}^{\{0,1\}}(A)$ relying on a similar argument identifying if and where $E_W(W, A) < 1$ for a range of cash values closes to $-(1 - \Theta) \times A$ for each value of A.

(e) We update the equity issuance boundary $\widetilde{W}^{\{0,1\}}(A)$ that defines the amount of equity to be issue using the value-matching condition.

$$E(\underline{W}^{\{0,1\}}(A), A) - E(\widetilde{W}^{\{0,1\}}(A), A) - \phi - (1+\gamma) \times (\widetilde{W}^{\{0,1\}}(A) - \underline{W}^{\{0,1\}}(A)) = 0 \tag{A-24}$$

and using the smooth pasting condition

$$E_W(\widetilde{W}^{\{0,1\}}(A), A) = 1 + \gamma.$$

The bank's shareholders prefer issuing larger equity amounts when $E_W(W, A) > 1+\gamma$. Because of numerical error due to the discretisation, equation (A-24) never holds exactly, so one checks whether it holds to within some specific bound ϵ, where ϵ is chosen arbitrarily (setting $\epsilon = \Delta W/2$ tends to work well). For W below $\underline{W}^{\{0,1\}}(A)$, shareholders may prefer refinancing over liquidation. In that case they refinance the bank back to $\widetilde{W}^{\{0,1\}}(A)$ as far as the equity value is not negative otherwise they liquidate. We repeat steps (a), (b), (c), (d) and (e) as far as $E^{\{0,j\}}(W, A) \geq 0$.

2. **Value function -** We solve the resulting PDEs (A-6), (A-8), (A-15) and (A-16) to find the equity value $E^{\{1,j\}}$, the market value of debt $D^{\{1,j\}}$ and the market value of unsecured deposits $M^{\{1,j\}}$ in the inaction region $B^{\{1,j\}}$.

So we repeat the two-step procedure $(1)-(2)$ up to the resolution of our code when the dividend, equity and cash boundaries converge. Thus, we terminate the process.

A-I.4.4 Equity dilution and Monte Carlo simulation

To compute the equity dilution share we follow Bolton, Wang, and Yang (2019). When the bank incurs an external financing cost $\phi + \gamma \times (\widetilde{W}(A) - \underline{W}(A))$ as it raises equity $\widetilde{W}(A) - \underline{W}(A)$ at any time t, the bank's post-issuance equity value is $E(W_{t+}, A_{t+})$. We can denote by η_{t+} the fraction of the newly issued equity held by outside investors:

$$\eta_{t+} = \frac{\phi + (1+\gamma) \times (\widetilde{W}(A) - \underline{W}(A))}{E(W_{t+}, A_{t+})} = 1 - \frac{E(W_t, A_t)}{E(W_{t+}, A_{t+})} \tag{A-25}$$

given the boundary condition

$$E(W_t, A_t) = E(W_{t+}, A_{t+}) - \phi - (1+\gamma) \times (\widetilde{W}(A) - \underline{W}(A)). \tag{A-26}$$

Via Monte Carlo simulation, we can highlight the dynamics of equity dilution by keeping track of the equity ownership of the original investors who have established the bank at $t = 0$. We denote by ζ_t the ownership share of the original equity holders at time t (where $\zeta_0 = 1$ or (100%) at $t = 0$). As the bank issues equity to finance investment and/or replenish liquidity over time, the original equity investors' ownership evolves as follows:

$$\zeta_{t+} = \zeta_t \times (1 - \eta_{t+}). \tag{A-27}$$

With no issuance $\eta_{t+} = 0$ and $\zeta_{t+} = \zeta_t$. But when new equity is issued at time t, with a strictly positive ownership stake for new investors of $\zeta_{t+} > 0$, the original equity investors' equity is diluted to η_{t+} from η_t according to Equation (A-27).

We simulate $50,000$ paths for the asset portfolio A and cash W state variables for 15 years on a monthly frequency. In the earnings retention region, the dynamics are

$$\begin{aligned}
dA_t &= \left(-\frac{A_t}{\delta} + I_t^*\right) dt + A_t dX_t \\
dW_t &= (r - \lambda)W_t + \frac{A_t}{\delta} dt - I_t^* dt - g(I_t^*, \rho)dt \\
&\quad - C^S dt - C^D dt + \frac{1}{m^D}(D(W, A, m^D; s^D) - P^D)dt \\
&\quad - C^U dt + \frac{1}{m^U}(D(W, A, m^U; s^U) - P^U)dt \qquad \text{if} \quad W_t \geq 0 \\
dW_t &= (r + s^{CB})W_t + \frac{A_t}{\delta} dt - I_t^* dt - g(I_t^*, \rho)dt \\
&\quad - C^S dt - C^D dt + \frac{1}{m^D}(D(W, A, m^D; s^D) - P^D)dt \\
&\quad - C^U dt + \frac{1}{m^U}(D(W, A, m^U; s^U) - P^U)dt \qquad \text{if} \quad W_t < 0
\end{aligned}$$

where

$$dX_t = (r + \widetilde{\mu}^X)dt + \sigma^X dZ_t,$$

and Z_t is simulated and used for the counterfactual and central bank case.

For each simulation path, we use the optimal investment policy $I_t^* = I^*(W, A)$ to trace the optimal evolution of A and W. We approximate continuous time by evaluating investment rules at discrete time intervals Δt (i.e. monthly) given realisations of W and A.

The only approximation in moving from continuous to discrete time is that the bank is allowed to adjust the cash variable only at discrete time. This occurs when i) $W(A)$ hits the cash boundary $\overline{W}(A)$ ($\overline{W}(A) > 0$) and the bank distributes dividends; and ii) $W(A)$ hits the CB cash boundary $\underline{W}(A)$ ($\underline{W}(A) < 0$). In the equity financing case, the bank issues equity and $W(A)$ readjusts to the optimal point $\widetilde{W}(A)$. Alternatively, shareholders prefer liquidation. Finally A might hit the closure boundary and the bank stops to operate.

A-I.5 Additional figures

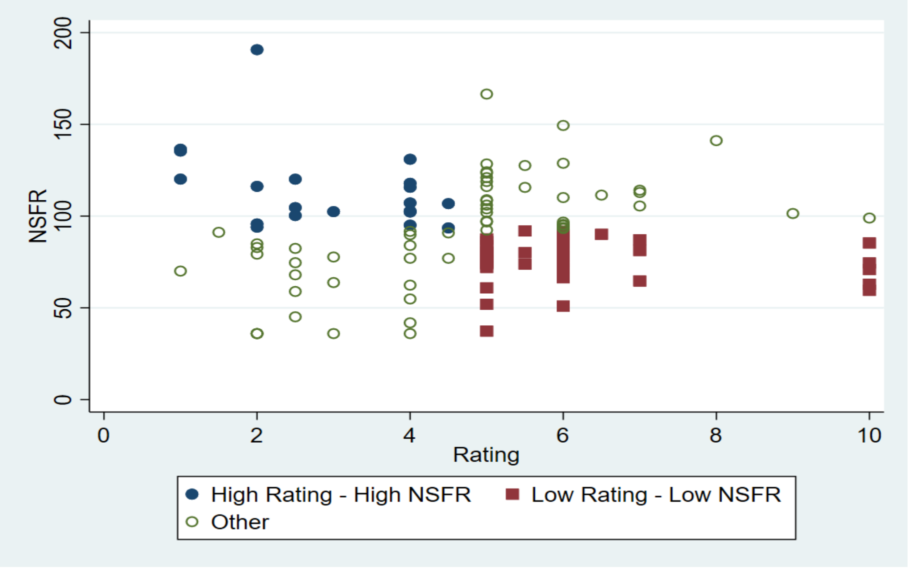

Figure A-IV: Rating vs NSFR - August 2007

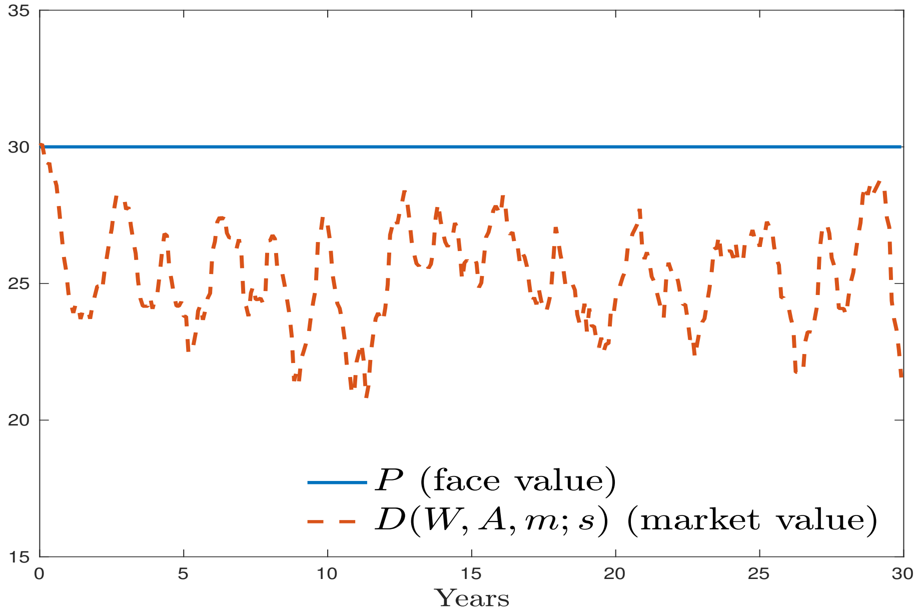

Figure A-V: **Debt market value for a simulated path -** This figure plots a simulated path of the market value of debt $D(W, A, m; s)$ with a principal $P = 30$.

Figure A-VI: **Capital structure over time -** The figure plots the average time series of the main liability categories based on the weights that are used for the NSFR computation (see Table A-I of the Appendix) for the HH group (top panel) and the LL group (bottom panel). The liabilities categories are scaled by total assets.

Acknowledgements

This project was initiated when the second author visited the ECB in 2015 as Wim Duisenberg Research Fellow. The hospitality extended by the ECB is acknowledged with thanks. We appreciate the comments provided by Viral Acharya, Sriya Anbil (discussant), Fernando Alvarez, Ulrich Bindseil, Markus Brunnermeier, Pierre Collin-Dufresne, Russell Cooper (discussant), Maximilian Guennewig (discussant), Philipp Hartmann, Florian Heider, Marie Hoerova, Tobias Linzert, Benjamin Moll, Steven Ongena, Urban Jermann, Marcin Kacperczyk, Nobuhiro Kiyotaki, Ralph Koijen, Arvind Krishnamurthy, Daniel Paravisini, Monika Piazzesi, Angelo Ranaldo, Rafael Repullo, Jean-Charles Rochet, Glenn Schepens, Tanju Yorulmazer (discussant), Skander Van den Heuvel, and ECB Directorate General Market Operations colleagues and the participants in seminars at the Bank of England, ECB, FRIC 2018, FIRS 2019, EFA 2019 and University of British Columbia. Francesca Barbiero, Veronica De Falco, Niklas Grimm, Alex Osberghaus and Alberto Venturin provided outstanding research assistance. Previous versions of this paper circulated under the title "Illiquidity, Closure Policies and the Role of LOLR".
The views expressed here are the authors' and do not necessarily reflect those of the ECB or the Eurosystem.

Stefano Corradin
European Central Bank, Frankfurt am Main, Germany; email: stefano.corradin@ecb.europa.eu

Suresh Sundaresan
Columbia University, New York, United States; email: ms122@columbia.edu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

PDF ISBN 978-92-899-5386-3 ISSN 1725-2806 doi:10.2866/931984 QB-AR-22-103-EN-N