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Stefano Corradin, Suresh Sundaresan

**LOLR policies, banks' borrowing
capacities and funding structures**

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Abstract

We develop a dynamic model of a bank which finances its asset portfolio by rolling over short-term deposits with access to LOLR liquidity. Bank faces frictions in equity issuance and loan portfolio adjustments. We calibrate our model with bank's estimated borrowing capacity at the LOLR and funding profile. We show that rollover of debt combined with access to LOLR results in a wealth transfer from private creditors to equity holders through increased dividend payments in good states, coupled with more risk-taking and defaults in bad states. The effects are stronger for banks with more fragile funding and higher maturity intermediation.

Keywords: Lender of last resort; short-term debt financing; rollover risk; risk-taking; financing frictions; liquidation.

JEL Classification Numbers: E58, G21, G32, G33, G35.

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 and persistent liquidity assistance to banks, under a changing liquidity provision and collateral policy framework. The liquidity provision changed in October 2008 discontinuing the practice to auction a pre-set quantity of liquidity and moving to full allotment tenders at a fixed rate. The tenors of longer term refinancing operations (LTROs) were extended from the pre-crisis standard of three months to one-year in 2009 followed by three-year LTROs in 2011 and 2012. The universe of collateral was also expanded via eligibility and haircut policies. ECB's use of fixed-price, unlimited lending with full allotments and LTROs was perceived to represent the fulfilment of its role as the lender of last resort (LOLR) (see Constâncio (2014) and Praet (2016)). Banks increased their reliance on ECB liquidity during the period spanning the GFC and euro area sovereign debt crisis as illustrated by Figure 1. The ECB kept offering favourable funding after the euro area sovereign debt crisis, when the main ECB policy rate was lowered into negative territory in 2014, and during the Covid-19 crisis (see Schnabel (2023)).¹

Using novel data sets and a dynamic calibrated model of banking, we document how banks, faced with *more fragile funding* [with potentially costly rollover of short-term private debt], differentially responded to ECB's sustained provision of ample liquidity, and its collateral policies in choosing their privately optimal choice of lending, defaults, equity issuance, and dividends. We further identify the potential channels for such a differential response. We shed light on the long-term implications of having a permanent and broad access to central bank (CB) liquidity. Although having access to CB liquidity substantially mitigates the bank's underinvestment problem in a crisis, keeping the LOLR policies for too long can result in a wealth transfer from creditors to equity holders through increased dividend payments in good states, coupled with more risk-taking and earlier liquidation in bad states.

Central to our theoretical investigation is a counterfactual: How might banks have chosen their optimal decisions, when their access to CB liquidity facilities is more limited? Answering this question is critical to fully comprehend how banks tailor their responses to the terms of CB liquidity provision, and its collateral policies. To this end, we develop a dynamic model of a bank which finances its optimal long-term loan portfolio by rolling over fairly priced short-term private deposits and debt and accesses LOLR liquidity, but it faces frictions in equity issuance, loan portfolio adjustments, asset liquidation and is subject to

¹After the euro area sovereign debt crisis, the ECB offered banks a series of targeted longer-term refinancing operations (TLTROs) with a maturity of three years to support lending. The ECB also provided strong monetary incentives for banks to maintain their lending to the real economy under TLTROs during the Covid-19 crisis.

regulatory requirements by resolution authorities. This is helpful in assessing the value of CB liquidity to banks and how banks adjust their key decisions in response to the terms of CB liquidity policies. We calibrate our model to our empirical evidence and examine the *differential response of banks* to CB'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 considering risky banks' funding structure and varying margins on eligible collateral to trace out the implications for banks' decisions on loan investments, defaults, dividends and equity issuances.

1.1 Summary of key results

In Section 4 we provide evidence that banks with lower ex-ante funding profiles relied more on ECB liquidity after controlling for the rating or risk-taking (Drechsler et al. (2016)), following the GFC and euro area sovereign debt crisis relative to banks with stronger ex-ante funding profiles. This result provides evidence in support of the traditional role of ECB as a LOLR. We use a novel 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 (see Section 3). Using bank level time series going back to August 2007 at *monthly frequency*, we construct estimates of *ex-ante* funding profiles of banks as measured by the Net Stable Funding Ratio (NSFR) that was introduced by Basel III and designed to reduce funding risk arising from the mismatch between assets and liabilities. We document that the most significant difference between *ex ante* low NSFR and high NSFR-banks is in terms of unstable funding as such interbank deposits, repo funding, commercial paper and short-term deposits with non-financial corporations. The *ex ante* low NSFR-bank has an average share of unstable funding of 54% with an average time-to-maturity of 0.22 years.

A major challenge in the literature is to assess the bank's borrowing capacity with the ECB. We develop a novel time-varying and bank-level measure using our data sets on banks' asset holdings and ECB eligibility and haircuts criteria. The borrowing capacity provides an estimate on the bank's ability to draw liquidity at the ECB in the full allotment regime. Here, we build on the work of Garleanu and Pedersen (2011), which shows the importance of haircuts on assets. This is also similar to the spirit of the contribution of Bai, Krishnamurthy, and Weymuller (2018) who quantify the mismatch between the market liquidity of assets and the funding liquidity of liabilities.² The average borrowing capacity is around 26% when we

²Jasova et al. (2023) provide empirical evidence that ECB haircut policy affects bank interconnectedness. They use micro-level dataset that links the securities held and pledged by banks to obtain ECB funding with the haircuts applied by the ECB and by private repo markets. They examine the haircut gap (or haircut

include all the potential eligible assets (marketable securities and loans). Our empirical results show a strong positive correlation between the borrowing capacity of banks and their take-up of ECB liquidity.³

Motivated by both the empirical evidence that bank's funding structure affects the reliance on ECB liquidity, as well as by the empirical importance of estimating how much liquidity a bank might draw from ECB, Section 5 develops a new model that preserves a role for risky private funding structure while accounting for the reliance on CB funding. We combine two strands of literature considering two main ingredients: i) the bank must choose its optimal long-term loan portfolio size subject to adjustment costs and faces external financing costs; and ii) the bank has to finance its loan portfolio by rolling over fairly priced short-term debt and deposits. As in Leland and Toft (1996), Leland (1998), He and Xiong (2012) and Della Seta, Morellec, and Zucchi (2020), the bank rolls over a short-term bond at market price when it matures. When the proceeds from debt rollover are lower than the principal of the maturing bond, the bank bears rollover losses. This modelling choice is motivated by our empirical finding that banks primarily differ in terms of the extent of their reliance on fragile funding sources. We thus extend the insights of the seminal papers by Bolton, Chen, and Wang (2011) and Décamps et al. (2011) who assume that firms' equity holders can change investment subject to adjustment costs and face external financing costs in terms of costly equity issuance which may lead to forced and inefficient liquidations. In this literature, debt is either absent or has infinite maturity.⁴ Our framework relates to the dynamic banking models of De Nicolo, Gamba, and Lucchetta (2014), Hugonnier and Morellec (2017) and Subramanian and Yang (2020), who analyse the impact of bank regulation, and also contributes to the recent literature on the duration of bank deposits (see Drechsler, Savov, and Schnabl (2021), Jermann and Xiang (2023) and Bolton et al. (2023)).

In our setting, equity holders take on additional debt accessing to LOLR via a credit line that mimics the ECB's full allotment tender procedure. The limit of the credit line depends on the asset holdings and the CB's haircuts, consistent with our borrowing capacity

subsidy): the difference in valuation haircuts applied by the private market and the CB for securities that can be pledged as collateral in repo operations.

³Drechsler et al. (2016) show that weakly-capitalized banks borrowed more from the CB. 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 that the collateral framework of the CBs may have a distortionary effect biasing the private provision of liquidity.

⁴Bolton, Chen, and Wang (2014) analyse a model of optimal capital structure and liquidity choice. They introduce a cost of issuing equity for the firm, which generates a precautionary demand for liquidity and an optimal liquidity management policy. Debt payments drain liquidity reserves and thus impose higher expected external financing costs on the firm. They model debt as a potentially risky perpetuity with regular coupon payment.

measure. Together, the costly rollover feature combined with having access to LOLR affect optimal policy decisions of a bank in significant ways. CB liquidity changes in the bank's liability structure, relative to private debt and deposits level, to manage rollover losses and to reduce expected refinancing costs and the risk of inefficient liquidation. Equity holders take into account not only of the current stock of funding but also of the information about the long-term loan portfolio prospects contained in current asset shocks. Thus, we provide a significant generalisation of a financially constrained bank's dynamic optimisation problem to two dimensions – loan portfolio and liquidity – in contrast to the earlier contributions with one of the two variables as the single state variable. Despite the significantly more complex formulation of the two-dimensional problem, we are still able to provide a tractable analysis of this problem.

In Section 6, with the parameters informed by our empirical work we calibrate our model on two groups who differ mainly on their funding structures in August 2007 (low-NSFR vs high-NSFR). Then, we evaluate the effects of funding structure and varying margins on eligible collateral on banks' decisions of having access to CB funding for an extended period considering a baseline and crisis scenario. We deliver the following three new insights. First, equity holders default more in illiquid states with a riskier funding structure (low-NSFR banks). This can lead to a wealth transfer from debt holders to equity holders. When bank's cash flows deteriorate, the market value of newly-issued short-term wholesale funding and debt decreases leading to rollover losses. Because the CB is senior to current creditors, the resulting lower payoff in liquidation leads to larger rollover losses when the bank approaches distress. In this scenario, equity holders can prefer liquidation instead of issuing equity.

Second, banks with greater access to LOLR on average tend to invest more in new loans. This result resonates favourably with the primary objective of the LOLR in supporting the lending channel and is consistent with the quantitative predictions of Bocola (2016) and De Fiore, Hoerova, and Uhlig (2018) and recent empirical literature (Alves, Bonfim, and Soares (2021), Carpinelli and Crosignani (2021) and Jasova, Mendicino, and Supera (2021)). However, we show that equity holders may have the incentives to substantially increase the exposure to risky loan portfolio when the bank approaches distress in the presence of LOLR, especially in a crisis scenario (Acharya and Steffen (2015), Diamond and Rajan (2011) and Puriya et al. (2016)). In our framework they do so to improve short-term debt repricing. This effect is magnified when the bank has a larger borrowing capacity with CB.

Third, the bank holds lower cash buffers, pays more dividends in good states and issues equity less often when it has access to CB liquidity facilities relative to the case in which it has a reduced borrowing capacity. The increased dividend payments with access to LOLR is to be viewed in the context of Stein (2013) who notes: “.. *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 euro area 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). A similar debate arose during the Covid-19 crisis when the ECB, among other CBs, asked banks to refrain from or limit dividends (see Blank et al. (2020)).

Figure 2 plots the distribution of 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 2014. 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 CB will lend to them in bad states, limited by only their borrowing capacity. In our policy experiments (see Section 6.3) we show that "tougher" collateral policies, namely higher haircuts and stricter eligibility criteria can mitigate these incentives.

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. The ECB mainly engages in two types of operations: main refinancing operations (MRO) and longer-term refinancing operations (LTRO).⁵ MROs are regular liquidity-providing transactions with a weekly frequency and a maturity of one week. LTROs are liquidity-providing transactions offered every other

⁵In 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 CBs (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.

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”.⁶ Second, the ECB provides liquidity to banks against collateral. The latter refers to marketable financial securities, such as bonds,⁷ or non-marketable assets, such as loans (or credit claims).⁸ 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 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.⁹ 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 (see Bindseil (2013)).¹⁰

3 Data

3.1 Bank characteristics and ECB borrowing

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,

⁶See https://www.ecb.europa.eu/press/pr/date/2011/html/pr111208_1.en.html.

⁷ECB-eligible marketable assets are generally euro-denominated investment-grade debt, such as sovereign debt, mortgage-backed bonds, covered bonds, bank bonds and corporate bonds.

⁸Three 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.

⁹However, the ECB may at any time apply additional risk control measures at the level of individual counterparties if required to ensure adequate risk protection.

¹⁰Conceptually, this may tilt ECB to prefer that banks issue equity in bad states as opposed to debt, which is *pari passu*.

while Bankscope data have a yearly (or quarterly) frequency. Finally, IBSI provides novel 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 Centralized Security Database (CSDB) to construct a panel of bank-level yield of external bank debt to measure the bank spread between the bank debt yield and the AAA-rated euro area central government bond yield with the same time-to-maturity and debt maturity.¹¹ This will be helpful later to calibrate our model. Second, 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). Third, 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. Finally, 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 and S&P). 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.

Overall, we construct a balanced panel of 197 euro area banks. We winsorize all variables at the 1th and 99th percentiles to reduce the impact of outliers. 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.¹²

¹¹The ECB estimates zero-coupon yield curves for the AAA-rated euro area central government bond yields using a Svensson model. Daily yield curves are calculated and released on a daily basis. See https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/euro_area_yield_curves/html/index.en.html.

¹²The entity in Drechsler et al. (2016) (who use Bankscope) is the banking group implicitly assuming that CB liquidity can be re-allocated within the banking group. However, only single MFIs have access to National Central Banks' 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.

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. 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.

The most usual dividend frequency is yearly and issuing equity is rare. On average, 13% of the banks issue equity in a given year with an average equity issuance over equity of almost 16% (see Panel C of Table 1). On average, 40% of the banks pay dividends in a given year with an average dividends' payment over equity of 2%.

3.2 Funding 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).¹³ This will serve as a measure of the funding and liquidity profile of the banks.¹⁴ 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.1 of the Internet 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 (see Sundaresan and Xiao (2024)). We prefer NSFR for the following reasons: i) it proxies for long-term funding needs which we will document with our data later; and ii) it is more "assumption free" while LCR requires modelling the expected outflows of the

¹³IBSI 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.

¹⁴This measure cannot be computed for banks located in France. The IBSI asset and liabilities categories shown in Table A.1 of the Internet Appendix are not reported for banks located in France in the first part of our sample (July 2007 - April 2010).

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 NSFR requirements during the GFC and euro area sovereign debt crisis.

3.3 Borrowing capacity with the ECB

One key empirical challenge is to measure the 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.¹⁵ We overcome this limitation implementing a novel approach to gauge the borrowing capacity with the ECB. We provide here a brief overview but Section A-I of the Appendix provides step-by-step details about how we construct our borrowing measure.

ECB collateral includes marketable financial securities, such as fixed-income securities, and non-marketable assets, such as loans. For marketable assets, we use data on security-level portfolio holdings of euro area investors from the Securities Holding Statistics (SHS). For each country, we compute how much the banking sector holds a specific security over its outstanding amount in a specific quarter. Thus, we merge the SHS with data on the eligible securities published by the ECB to verify whether a specific security in SHS is eligible for ECB liquidity operations and the haircut applied by the ECB if the security is eligible. Finally, we link the holdings data to IBSI to compute the aggregate ECB haircut on the main IBSI asset balance sheet items at bank 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. As shown in Figure A-III, the fixed income holdings of a bank does not proxy the borrowing capacity on the same portfolio due to the time-varying ECB eligibility criteria 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

¹⁵Drechsler et al. (2016) for example use information on bank holdings of distressed-sovereign debt published for the euro area bank stress tests. However, euro area 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.

2009 – 2015 and investigate the time-series and cross-sectional patterns of such measure.¹⁶

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 markets, therefore we cannot quantify the fraction of encumbered securities. Second, the use of non-marketable as collateral is perceived by counterparties costly compared with marketable assets. As 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 27%, but there is a significant cross-sectional variation in the borrowing capacity of the banks: the 10th percentile is around 8% while the 90th percentile is around 47%. 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%.

In the Appendix (see Table A-II), we provide a formal empirical analysis of the banks' borrowing capacity. 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. Additionally, we observe that the rating coefficient is not statistically significant suggesting that riskier banks do not necessarily have a larger borrowing capacity to rely on ECB liquidity.

4 Empirical evidence

We begin this section examining how the NSFR and our borrowing capacity measure correlate with the ECB liquidity take-up and the informativeness of the NSFR in predicting a bank's borrowing decision during the GFC and the euro area sovereign debt crisis. Finally, NSFR depends on assets and liabilities but we document that the liability side plays a larger role before the GFC.

4.1 Bank liquidity profile and borrowing capacity

We empirically analyse the relation between the liquidity take-up at the ECB and the time-varying NSFR and borrowing capacity for marketable assets measures during the GFC and

¹⁶The SHS data are collected on a quarterly basis in the euro area since the first quarter of 2009.

the euro area sovereign debt crisis.¹⁷ This exercise is also informative for the model specification in the next section to identify the main variables affecting the banks' borrowing decision at the CB. We estimate the following regression model:

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

where the controls $X_{i,t}$ includes assets (in natural logarithms), the capital ratio which may indicate a need to borrow from the CB and the bank rating when available. All the explanatory variables are month-lagged. The results are reported in Table 2. 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 $\log(\text{ECB liquidity take-up} + 1)$ to account for the banks that do not rely on ECB liquidity [see Columns (1)-(5)]. We also restrict our specification to the banks who participated to the financing operations, $\log(\text{ECB liquidity take-up})$ [see Columns (6)-(7)]. 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 profiles and borrowing capacities. The effects of NSFR and borrowing capacity are confirmed when we interact the variable with a post GFC, 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)].

We next ask whether banks with a *worse pre-crisis NSFR* rely more on the ECB liquidity during the GFC 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.¹⁸ Thus, all controls

¹⁷The results are unaffected if we use the borrowing capacity measure that includes non-marketable assets.

¹⁸We cannot control for the borrowing capacity with ECB because this measure can be computed since

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 $\times$ time fixed effects ($\mu_{j,t}$) to capture time-series variation that is common to all banks within a country j . Standard errors are clustered at bank level. Specifically, we estimate the following regression:

$$y_{i,t} = \mu_{j,t} + \beta_t \times \text{NSFR}_i^{2007} \times \text{Post}_t + \epsilon_{i,t}, \quad (2)$$

where $y_{i,t}$ is 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 3 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 GFC after controlling for the rating or risk taking channel and other bank's characteristics [Columns (1) – (2)]. The results are statistically significant at 1% level when we restrict our specification to non-distressed countries [Column (2)]. 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 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 (3) – (4)]. 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 (3) – (4)].

4.2 NSFR decomposition: asset vs liability

Our previous results indicate that the NSFR is indeed informative of a bank's decision to rely on ECB funding. But is NSFR driven mostly by banks' liabilities or assets? To address this question, we then sort banks along the pre-crisis NSFR using the median 33rd and 66th percentiles as of August 2007. This allows us to construct two groups of banks: 1) banks with low NSFR and 2) banks with high NSFR. Table 4 reports the mean, the standard deviation and the results of a mean t-test for the main asset and liabilities categories for the first quarter of 2009.

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.1 of the Internet Appendix).

Low-NSFR banks are on average bigger than High-NSFR banks in terms of assets (€47,845 vs €31,231 million) but we also observe a large standard deviation for both groups (see Panel A). The t-test 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 4 examines potential differences in asset bank characteristics between the two groups. Bank assets mainly consist of corporate debt securities and loans, making up to 70.47% (66.05%) of total assets for High-NSFR (Low-NSFR) banks in August 2007.¹⁹ For some categories, the t-test accepts the hypothesis that the means are different from each other but the differences are not economically sizeable.

We then compute statistics and t-test for five main 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 Low-NSFR is almost 36% and is almost double than the High-NSFR unstable funding ratio (12%). High-NSFR banks rely more on households deposits and long-term debt (31.87% and 15.20%) than Low-NSFR banks (12.76% and 11.92%).

Finally, we do not observe any difference in terms of loans' and deposits' rates between the two groups (see Panel D).

Overall, our results suggest that the two groups differ mainly on their funding structures. In Figure B.2 of the Internet Appendix we also plot the evolution of the main NSFR categories for the liabilities showing that the average funding structures composition is stable over time for the two groups. The literature has tended to mainly emphasise the risk-taking channel of the asset side while we emphasise the funding channel. Table 4 also suggests to calibrate the model in terms of liability structure composition in August 2007 considering three main private debt contract-types: 1) unstable funding associated with a low weight in the NSFR ratio; 2) stable funding associated with a weight above 0.9 in NSFR ratio and 3) secured debt.

¹⁹We 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.

5 A micro dynamic model of banking

To understand the implications of our empirical findings for the banks' funding risk as well as its consequences for CB borrowing, we now proceed to build a micro dynamic banking model, which centrally features the interaction between funding structure, decision of issuing equity or liquidating and CB liquidity. We provide a novel framework combining two strands of literature: i) the bank must choose its optimal long-term loan portfolio size subject to adjustment costs and faces external financing costs as in Bolton, Chen, and Wang (2011), Décamps et al. (2011) and Hugonnier and Morellec (2017); and ii) the bank has to finance its loan portfolio by rolling over fairly priced short-term debt and deposits as in Leland and Toft (1996), Leland (1998), He and Xiong (2012) and Della Seta, Morellec, and Zucchi (2020). We lay out the key mechanisms of our model and the complete solution is provided in Section A-II of the Appendix.

The first state variable is the asset portfolio represented by A . It consists of loans and securities:

$$dA_t = \left(- \underbrace{\frac{1}{\delta}}_{\text{Assets' maturity}} A_t + \underbrace{I_t}_{\text{Investment policy}} \right) dt + \underbrace{A_t dX_t}_{\text{Loss or gain}}, \quad (3)$$

where $1/\delta$ is the rate at which the asset portfolio matures. Thus, the average maturity of the existing stock is δ .

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:

$$g(I_t) = \psi I_t^2. \quad (4)$$

The investment then satisfies the following first-order condition:

$$I_t = \frac{1}{2\psi} \left(\frac{E_A(W, A)}{E_W(W, A)} - 1 \right), \quad (5)$$

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 term $A_t dX_t$ in Equation (3) describes the additional law of motion components of

the asset portfolio, where dX_t is the bank's asset shock over time increment dt

$$dX_t = (r + \tilde{\mu}^X)dt + \sigma^X dZ_t + \xi^X dJ. \quad (6)$$

The parameters $\tilde{\mu}^X$ and σ^X are the risk premium and the volatility of the asset shocks dX_t . Z_t is a standard Brownian motion and $\xi^X dJ$ describes the jump term. We assume a deterministic and constant jump intensity, η^X . Thus, should a jump occur, its size is constant at ξ^X of market value A_t . The increments of the Brownian motion represent small and frequent shocks to the assets portfolio. The jumps of the Poisson process represent large losses that may be due, for example, to defaults across the assets portfolio (see Acharya et al. (2010), Hugonnier and Morellec (2017)) and will allow us to match the drop in return on assets we observe in the data during the euro area sovereign debt crisis.

We next turn to bank's cash state variable denoted by W_t that is the second state variable of our problem. When $W_t < 0$, the bank borrows from the CB. 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 $-\Theta \times A$. 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 Section 3. The CB has perfect information on asset portfolio value A .²⁰ 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 . We define A^B as the *ex ante* level of assets that is not covered by long-term stable funding P^S , $A^B = A_0 - P^S$.

The dynamics of the state variable W in the CB funding region evolves as

$$dW_t = (\underbrace{r + s^{CB}}_{\text{Cost of borrowing cash}})W_t + \underbrace{dY_t}_{\text{Bank's profits}} + \underbrace{dH_t}_{\text{Equity issuance}} - \underbrace{d\Phi(H_t)}_{\text{Equity issuance costs}} - \underbrace{dU_t}_{\text{Dividends' payment}}. \quad (7)$$

²⁰If the CB cannot value bank assets perfectly, it might end up providing funding to insolvent banks but it might make losses, or it might not provide funding to illiquid but solvent banks (Rochet and Vives (2004)). The anticipation of lending to insolvent banks also creates a moral hazard problem (see for example Acharya, Shin, and Yorulmazer (2011); and Farhi and Tirole (2012)). It may also induce banks to invest in riskier assets while holding fewer liquid assets (Repullo (2018)). Finally, Santos and Suarez (2019) show the benefits of having regulatory liquidity requirements when the uninformed CB has to provide funding to support troubled banks during a run.

The terms H_t and $\Phi(H_t)$ of the cash dynamics equation (7) refer to costly equity issuance. 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. Thus, 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 represents the bank's incremental operating profit cash flows dY_t over time increment dt

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

where A_t/δ 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 term in equation (8) are related to the debt service. 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 following Leland and Toft (1996), Leland (1998), He and Xiong (2012) and Della Seta, Morellec, and Zucchi (2020). 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. Thus the net refunding cost occurs at the rate $(1/m^D) \times (D(W, A; m^D, s^D) - P^D)$ 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. Note that when $D(W, A; m^D, s^D) < P^D$ shareholders face negative cash flows. Hence, the rollover can be expensive for the bank. 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.²¹ Then, we can assess the impact of a low NSFR ratio on the demand of CB liquidity that we have documented in the previous section.

A key feature of our framework is that shareholders may prefer voluntary liquidation instead of issuing costly equity before regulatory requirements are breached. There are two distinct features of our model that characterize this choice. First, the shareholders' 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 $D(W, A; m^D, s^D) < P^D$ 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 an liquidation hurdle in terms of the asset portfolio that we define A^* .

Shareholders may liquidate voluntarily before its regulatory requirements are breached in two circumstances. First, in the region $[A^B, A^*)$ shareholders are not willing to issue equity. Every time W hits the maximum limit of CB liquidity the bank can borrow, $\Theta \times A$, the bank is liquidated. Second, when $A \geq A^*$ shareholders issue equity: if W crosses the endogenous equity issuance boundary $\underline{W}(A)$, the shareholders issue equity reaching the level of cash $\widetilde{W}(A)$. Between $\underline{W}(A)$ and $\widetilde{W}(A)$ the marginal value of equity with respect to cash W is $E_W(W, A) \geq 1 + \gamma$. However, for any $W \leq \underline{W}(A)$, shareholders raise new equity and reset cash to $\widetilde{W}(A)$ as far as the equity value is positive as the shareholders always have the option to liquidate avoiding negative equity. We define the liquidation boundary as $\widehat{W}(A)$.

When $W_t \geq 0$, the bank is in the cash region, wherein the bank holds internal liquidity. The dynamics of the state variable W in the cash region is

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

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 cash balance, which potentially exposes the bank to current and future underinvestment

²¹The rollover risk also depends on the average maturity m^D : the lower the maturity of the debt the bank has to roll over the lower its NSFR ratio is.

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 $\bar{W}(A) > W$ or pay in dividends in the amount $W - \bar{W}(A)$, when $\bar{W}(A) < W$. Here $\bar{W}(A)$ 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 .

Shareholders choose investment I , payout policy U , external financing policy H , default τ policies to maximise shareholder value subject to i) the asset portfolio equation (3), ii) the cash equations (7) and (9), and iii) the boundary conditions (see Section A-II of the Appendix):

$$E(A, W) = \max_{I, U, H, \tau} E \left[\int_0^\tau e^{-rt} (dU_t - dH_t - \Phi(dH_t)) + e^{-r\tau} \max(l \times A_\tau - P^D - P^S, 0) \right]. \quad (10)$$

The first term represents the flow of dividends accruing to incumbent shareholders, net of the claim of new shareholders on future cash flows. Note that equity issuance hurts the value of existing shareholders. The second term represents the present value of the cash flow to shareholders in default. Finally, the optimal A^* is the one that maximises the equity value for the initial asset and cash levels A_0 and W_0 :

$$A^* = \operatorname{argmax}_A E(A, W; A_0, W_0). \quad (11)$$

6 Calibration, model solution and policy implications

In Section 6.1, 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 6.2. In Section 6.3, we provide implications for borrowing at LOLR, default probability, investment, payment of dividends and equity issuance for High and Low-NSFR 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.

6.1 Parameters

We use the stylized facts reported in Table 4 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) 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-II of the Appendix accounts for this extension. While our model is highly stylized, it does allow us to match the CB borrowing over assets distribution, the average investment over assets and the average return on assets. For each bank type, we simulate data 25,000 times generating 20 years of daily data (see Section B.3 of the Internet Appendix).

Panel A of Table 5 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 4, 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 4. We set the equity E_0 at 9 (6) and debt P_0^D at 15 (12) for High (Low)-NSFR bank, 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 39 (54) for High (Low)-NSFR bank. 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 5. Our dataset starts in August 2007 when we also differentiate the two groups of banks in terms of asset and liability characteristics. Therefore, we infer the model parameters over a longer period, August 2007 - April 2011 that excludes the euro area sovereign crisis period.²²

For the CB we have three key parameters. We set r at the average ECB deposit rate of 2.23%, while we set the CB penalty rate s^{CB} at 0.50% to match the average spread between the ECB refinancing rate and the ECB deposit rate over the same period. For the borrowing capacity we rely on our measure. The two groups have a similar borrowing capacity with ECB. The High (Low)-NSFR bank has an average borrowing capacity over assets, Θ , of 32.68% (29.56%). We verify whether the model performs well in the sample by checking whether it reproduces the key statistics of the CB borrowing over assets time series. The average CB borrowing over assets is 1.64% (3.28%) for High (Low)-NSFR bank in the data, while the average in the simulated data is 1.57% (2.95%) (see Table 6). The model performs well also in terms of matching the 10th, 50th and 90th percentiles of the distribution. In the data we observe $[0, 0, 5.56]$ ($[0, 1.41, 9.22]$) for High (Low)-NSFR bank, while in the simulated data we have $[0, 0, 6.20]$ ($[0, 0, 11.01]$) for High (Low)-NSFR bank. We also explore the implications for our main results of varying Θ . Thus, we change Θ from 32.68% (29.56%) to 12.84% (11.96%) where the latter one is based on the average borrowing

²²This period is easier to analyze in terms of key moments because the main parameters are not affected by sovereign risk that characterises the euro area sovereign debt crisis.

capacity over assets computed on fixed-income security holdings.

For the assets, we set the loans' maturity parameter δ at 10.09 (10.96) years for High (Low)-NSFR bank based on the weighted average loans' maturity. The weight is the nominal amount of loans at bank level. 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 B.2 of the Internet Appendix. We estimate a volatility parameter of 9.21% (9.29%) for the High (Low)-NSFR bank. Thus, we do not observe any substantial difference in terms of asset risk between the two groups. The shareholders require a risk premium $\tilde{\mu}^X$ which we set to 3.4% (3.2%) for the High (Low)-NSFR bank to target the low average return on assets (ROA) we observe in the data as illustrated by Figure 8 (see also Altavilla, Boucinha, and Peydró (2018)²³). For the High (Low)-NSFR bank our simulation results provide an average ROA of 1.02% (0.96%). We set the jump arrival rate η^X of 2.5% and ξ^X of 20% which implies that each jump arrival causes an expected (percentage) asset loss of 20% of the asset market value and asset portfolio on average jumps downward about once every 40 ($= 1/0.025$) years. These parameters allows us to capture the drop in ROA we observe during the euro area debt crisis (see Figure 8). In our crisis scenario our simulation results provide an average ROA of -0.7% (-0.19%) for the High (Low)-NSFR bank.

From the literature we pick the value of the opportunity cost of cash λ setting to 1% (see Bolton, Chen, and Wang (2011) and Décamps et al. (2011)). Finally, we set the unit price of loan investment to 5% following De Nicolo, Gamba, and Lucchetta (2014). We observe the model performs reasonably well regarding investment behaviour. The average investment over assets in the simulated data is 5.83% (5.81%) for High (Low)-NSFR bank (see Table 7). In the data, we observe a lower average of 4.28% (4.02%) for High (Low)-NSFR bank, but our implied distribution looking at the 10th, 50th and 90th percentiles still captures key features of the empirical distribution. In the data we observe [1.41, 3.12, 7.97] ([1.25, 3.31, 9.46]) for High (Low)-NSFR bank, while in the simulated data we have [4.30, 5.46, 7.78] ([4.01, 5.31, 8.10]) for High (Low)-NSFR bank.

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.²⁴ The average time-to-maturity of the unstable funding, m^U , is 0.17 (0.21) years for High (Low)-NSFR type. The average

²³Altavilla, Boucinha, and Peydró (2018) document that bank profitability in the euro area showed an increasing trend in the run-up to the GFC, followed by a decline reflecting an abrupt increase in loan loss provisions during the euro area sovereign debt crisis.

²⁴We use the CSDB that provides information on all individual securities issued in the euro area but the data starts in 2009.

spread s^U is 0.16% for High-NSFR type, while it is 0.77% for Low-NSFR type over the same period. Our estimates of the spreads of unstable deposits complement our previous empirical findings. Low-NSFR 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. 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 3.01 (3.37) years for High (Low)-NSFR type. The mean spread s^D is 0.95% (0.86%) for High (Low)-NSFR bank.

For the cost of issuing equity, the parameters γ and ϕ are set to values that are common in the literature. We set the proportional equity issuance cost γ to 5.5% (Altinkilic and Hansen (2000)). For the fixed equity issuance cost ϕ we are not aware of no empirical study on which we can rely for the estimates of issuance costs in a financial crisis for the reason that there are very few initial public offerings or secondary equity offerings in a crisis (see also Bolton, Chen, and Wang (2013)).²⁵ Alternatively, our statistics for the equity amount issued and the frequency of equity issuance could guide us but unfortunately for our sample we also have few observations and it is also hard to distinguish between the two bank groups (see Table 1). As baseline we set ϕ to 2 and we show later how a decrease in the cost affects the model boundaries.

Finally, as in Huang and Huang (2012) and others, we target the liquidation proportion l for debt holders when the bank defaults to 35% of the debt and unstable deposits face value in absence of the CB.²⁶ We obtain a liquidation proportion parameter of 0.9 (0.72) for the High (Low)-NSFR bank.

6.2 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. We describe the numerical algorithm in detail in Section B.1 of Internet Appendix. We highlight here two distinct challenges. First, the HJB equations for the equity value, $E(W, A)$, and market debt values, $D(W, A; m^D, s^D)$, are coupled and one therefore has to iterate on them.

²⁵In Bolton, Chen, and Wang (2013), a firm optimally manages its cash reserves, financing, and payout decisions by following a state-dependent (two-regime) optimal double-barrier policy for issuance and payout, combined with continuous adjustments of investment and cash accumulation. Hugonnier, Malamud, and Morellec (2015) also develop a dynamic model with stochastic financing conditions. They model the window of financing opportunities via a Poisson process. When such an opportunity arrives, the firm has to decide immediately whether to raise funds or not.

²⁶Specifically, we have $l = (35\% \times (P_0^U + P_0^D) + P_0^S)/A_B$.

Second, solving these differential equations requires dealing with a two-dimensional free-boundary problem where the HJB equations and the domain over which the HJBs must be solved need to be determined simultaneously. For our problem we need to compute three endogenous boundaries: the dividend boundary $\overline{W}(A)$, the cash level after equity issuance boundary $\widetilde{W}(A)$ and the equity issuance boundary $\underline{W}(A)$.

We present here the solution for the High-NSFR bank. To gain some intuition we first discuss how the liquidation and equity issuance decisions are affected by costs of issuing equity and short-term debt with rollover risk. The top panel of Figure 3 plots the cash level after equity issuance boundary $\widetilde{W}(A)$ for any pair (W, A) setting the fixed cost of issuing equity ϕ at 2. The amount of CB liquidity is limited by two exogenous boundaries. The first one is the solvency boundary defined by $A^B (= 62)$. 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 $-\Theta \times A$. Based on Table 5, Θ is at 32.68%.

The equity value at initial levels A_0 and W_0 is maximized at $A^* = 65$ [$E^*(A_0, W_0) = 69.56$]. In the region $[A^B, A^*)$ highlighted by the grey area in the top panel of Figure 3 shareholders are not willing to issue equity. Every time W hits the maximum limit of central bank liquidity the bank can borrow, $-\Theta \times A$, the bank is liquidated. When $A \geq A^*$ shareholders issue equity reaching the level of cash $\widetilde{W}(A)$ (blue dashed line). We now decrease the fixed cost ϕ to 0.1 and therefore shareholders face almost no fixed external financing costs (recall that we still have the marginal cost of issuing equity γ). As expected, the equity value substantially increases when we decrease ϕ , $E^*(A_0, W_0) = 77.77$. More importantly the maximum is reached at $A^* = 62$ and as result A^* now coincides with A^B indicating that shareholders are now willing to issue equity for any level of assets. Therefore, we do not have any liquidation inaction region where shareholders could liquidate the bank when cash crosses the borrowing capacity with CB. As displayed in the top panel of Figure 3, the cash level after equity issuance boundary $\widetilde{W}(A)$ (red line) now starts at A^B and shareholders issue less equity because the boundary is now lower.

In the bottom panel of Figure 3, we display the equity issuance boundary $\underline{W}(A)$ and the liquidation boundary $\widehat{W}(A)$. When $A \geq A^*$ shareholders issue equity when W crosses the endogenous boundary $\underline{W}(A)$ reaching the level of cash $\widetilde{W}(A)$. For our set of parameters, $\underline{W}(A)$ (continuous blue line) is well above the borrowing capacity $-\Theta \times A$ when A is close to A^* (from the right) implying that for levels of A close to A^* shareholders issue equity before exhausting the borrowing capacity with CB. The endogenous boundary $\underline{W}(A)$ strictly decreases with A implying that shareholders are more willing to borrow from the CB when A increases and as result the equity issuance boundary $\underline{W}(A)$ overlaps with the borrowing capacity $-\Theta \times A$. For any $W < \underline{W}(A)$, we verify whether equity issuance or liquidation

is optimal, as shareholders always have the option to liquidate avoiding negative equity. When the liquidity shortfall is large and falls below liquidation boundary $\widehat{W}(A)$ (dashed blue line), shareholders prefer liquidating the bank. Note that when A increases, shareholders issue equity in the area delimited by the borrowing capacity $-\Theta \times A$ and the liquidation boundary $\widehat{W}(A)$. When we decrease the fixed cost issuing equity ($\phi = 0.1$), shareholders are less conservative. First, because issuing equity is less costly, they do not rely on the entire borrowing capacity with CB when A approaches $A^B = A^*$. Second, they are more willing to issue equity as shown by the larger area delimited by the liquidation boundary $\widehat{W}(A)$ (dash-dotted red line) and the equity issuance boundary $\underline{W}(A)$ (continuous red line).

We now analyze the impact of debt maturity increasing the maturity of unsecured deposits m^U from 0.17 to 10 years.²⁷ Because short-term debt holders have full information, the price at which maturing short-term debt is rolled over reflects the shareholders' decisions in terms of investment, dividend payout and equity issuance vs liquidation decision. This determines the magnitude of rollover imbalances and feeds back into the value of equity affecting equity holders' incentives. A shortening of maturity implies an increase in rollover losses and, thus, in the incentives of liquidating the bank as illustrated by Figure 4. First, when shareholders do not face rollover losses due to the increase in maturity debt, the equity value is maximised at $A^* = A^B$ ($E^*(A_0, W_0) = 83.58$). Thus, shareholders are always willing to issue equity for any level of asset A (continuous red line). This case 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 shareholders will not issue equity if the asset portfolio falls below it. Second, shareholders when facing no rollover risk optimally choose to rely less on internal funds and as result they will issue a smaller amount of equity when they will run of cash implying a lower $\widetilde{W}(A)$ bound (see top panel of Figure 4). Third, similarly to the low costs of issuing equity, shareholders are also more willing to issue equity as shown by the larger area delimited by the liquidation boundary $\widehat{W}(A)$ (dash-dotted red line) and the equity issuance boundary $\underline{W}(A)$ (continuous red line) (see bottom panel of Figure 4).

To further understand how financing frictions and short-term financing affects liquidation vs equity issuance decision, our next set of results focuses on market value of unsecured deposits. The top panel of Figure 5 plots the market value of the unstable deposits against asset A for two levels of cash. The principal value of unstable deposits P^U is set at 39. A first observation that emerges is that the market value of unstable deposits is increasing and concave in A , especially in the liquidation area $A^B \leq A < A^*$ ($A^B = 62$ and $A^* = 65$). Because shareholders prefer liquidation instead of costly equity issuance, unstable deposits

²⁷For consistency we increase the maturity of secured debt m^D from 3.01 to 10 years.

are risky leading to rollover losses $D^U(W, A; m^U, s^U) < P^U$. Note the rollover losses are large due to the very short maturity of unstable deposits we document in the calibration subsection, $m^U = 0.17$ (years) (see Figure B.4 of the Internet Appendix).²⁸ When the asset value increases, the bank is less likely to default, shareholders prefer issuing equity and therefore the market value of unstable deposits approaches the risk-free value.

The bottom panel of Figure 5 plots the market value of the unstable deposits against cash W for two levels of assets. As illustrated in the figure, when $A = 64$, the market value of unstable deposits is depressed because we are in the liquidation region as in Della Seta, Morellec, and Zucchi (2020). The market value of unstable deposits drops to the recovery value when W is below the liquidation boundary. If A increases, the market value jumps to the risk-free value because shareholders are now willing to issue equity. When the bank approaches the liquidation region also debt is risky leading to rollover losses although debt maturity is longer ($m^D = 3.01$ years) and the fraction of debt that needs to be rolled over on each time interval is smaller (see Figure B.3 of the Internet Appendix). Because unstable deposits and deposits are junior securities with a lower priority than CB liquidity, the payoff for creditors if shareholders liquidate the bank is depressed. The resulting lower payoff to creditors in liquidation leads to larger rollover losses when the bank is close to exhausting the credit line with the CB and as result the chances of liquidation increase.

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 High and Low-NSFR banks was pretty stable over time in our sample (see Figure B.2 of the Internet 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”. Third, as discussed in Della Seta, Morellec, and Zucchi (2020), adjusting debt level is not optimal for shareholders when the bank is close to distress.²⁹

Top panel of Figure 6 plots the investment-asset ratio and illustrates risk taking behaviour due to external financing constraints and rollover debt. Optimal investment is stable and

²⁸Rollover losses are defined as $(1/m^U) \times (D^U(W, A) - P^U)$.

²⁹In a first scenario, shareholders could take more debt to cover cash losses. As the face value of debt increases, shareholders would pay a much higher spread and rollover losses would get larger when the bank approaches distress. Overall, this magnifies shareholders’ incentives for liquidation. At the same time, the shareholders can still rely on CB funding at cheaper conditions. In a second scenario, shareholders could decrease leverage by buying back some of its debt at par value. Debt reductions would reduce the bank’s ability to cover cash losses, because the bank would need to use its cash balances to repurchase debt thereby getting even closer to default. Additionally, repurchasing debt in the region where the bank makes rollover losses would transfer wealth from shareholders to creditors, making it suboptimal for shareholders to buy back debt.

close to 5% when the bank's assets are high. But, when bank assets approach liquidation region, the bank shifts from safer into riskier asset exposure by placing a bet on its own survival (see for example Acharya and Steffen (2015), Diamond and Rajan (2011) and Puriya et al. (2016)). To increase assets, the bank needs to use its cash balances to invest more thereby getting even closer to default. When cash is sufficiently low and the bank is in the liquidation region, it will disinvest by selling assets to raise cash and move away from the liquidation boundary (see bottom panel of Figure 6). Note that disinvestment is costly not only because the bank is underinvesting but also because it incurs physical adjustment costs.

To conclude this section, we display all the optimal decisions - the dividend payout, borrowing with CB, equity issuance and liquidation regions - for any pair (W, A) in Figure 7. The inaction region (white area) is delimited by the dividend boundary $\bar{W}(A)$, the solvency boundary A^B , the borrowing capacity boundary $-\Theta \times A$ and the equity issuance boundary $\underline{W}(A)$. The drop in the dividend boundary $\bar{W}(A)$ when A approaches A^B is due to the assumption that equity holders cannot recover cash when default is triggered by regulatory authorities. The continuous blue line refers to the dividend payout boundary $\bar{W}(A)$: when $W > \bar{W}(A)$ the bank pays dividends in the amount $W - \bar{W}(A)$ (yellow area). 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 cash level after equity issuance boundary $\widehat{W}(A)$ is also convex and decreasing in the asset portfolio A . Therefore, the economic analysis of our two-dimensional problem is significantly enriched compared to frameworks that are linearly homogenous in cash and assets and would predict linear and positive boundaries as in Bolton, Chen, and Wang (2011). As previously discussed, within the inaction region we distinguish between two regions: liquidation and equity issuance. The endogenous asset value A^* separates these two areas. When (W, A) are low, it is optimal for the shareholders to abandon the bank as is indicated by the liquidation region (blue area). Instead, when the asset A grows and the bank relies on CB funding, shareholders prefer to issue equity as indicated by the equity issuance region delimited by the liquidation boundary $\widehat{W}(A)$ and the equity issuance boundary $\underline{W}(A)$ (and borrowing capacity $-\Theta \times A$) (green area).

6.3 Policy experiments: CB borrowing, default, equity issuance and dividends' payment

We use our model as a laboratory examining the effects of riskier funding structure (High vs Low-NSFR bank) and varying the CB borrowing capacity. We consider the larger value of the borrowing capacity based on loans and fixed income securities as reported in Table

5. For the High (Low)-NSFR type the borrowing capacity, Θ , is 32.68% (29.56%). We then consider a tighter borrowing capacity measure only based on fixed income securities: 12.84% (11.96%) for High (Low)-NSFR type.

To evaluate the effects on CB borrowing, default probability, investment, equity issuance and dividends' payment, we use our model simulations (see Section B.3 of the Internet Appendix). For all the results, we feed into the model the same realisations of the shocks, (dZ, dJ) . In order to make the exercise more realistic, we also choose the trajectories of our main variables so that the economy is in a crisis scenario ("bad state"). We do so by selecting state variables at which ROA computed on A falls below its 5th percentile over the simulation period proxying the drop in ROA we observe during the euro area debt crisis (see Figure 8).

To interpret the results, Figure 9 shows two simulated paths for asset portfolio A (Panel A), cash variable W (Panel B), rollover losses (Panel C) and equity dilution (Panel D). The blue line plots the baseline scenario ("good state"), while the red dotted line plots the crisis scenario ("bad state"). In the baseline scenario assets increase and the bank pays dividends after accumulating cash ($\bullet$ indicates where the dividends are paid in Panel B). The optimal payout policy consists in distributing dividends to maintain liquid reserves at or below the target level $\bar{W}(A)$ that depends on the level of assets A . In Panel C, rollover imbalances are positive showing that short-term debt financing may be attractive to equity holders in the good state, because the market value of unstable deposits and debt is larger than their principal values and so are the proceeds from debt rollover.

In the crisis scenario the bank starts relying on CB liquidity after downward jump in asset portfolio. The bank issues equity three times when cash flow shocks deplete the liquidity the bank can borrow from the CB ($\blacksquare$ indicates where the bank raises equity in Panel B). 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. As previously discussed, the risk of facing a large fixed cost of equity and rollover losses induces the bank to immediately move away from the equity issuance boundary $\underline{W}(A)$. Interestingly, in this scenario the banks' original shareholders are nearly wiped out after the two first equity issuances. Panel D summarises the implied equity ownership dynamics that follow from the bank's decisions over the simulated paths of W and A . Under the simulated "bad state" path, we 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 (W_0, A_0) as in Bolton, Wang, and Yang (2019).

Table 6 provides the numerical results for equity value (Column (2)), CB borrowing (over assets) (Column (3)), rollover losses (Column (4)) and default probability (Column

(5)) when the bank relies on CB liquidity. For CB borrowing (over assets) and rollover losses, we report the mean and the 10th, 50th and 90th percentiles in brackets for all the trajectories simulated. Immediately below, we also report the statistics for the crisis scenario. We do so to emphasise that the average provides an incomplete picture and the fat tails of the distribution are dramatically magnified in the crisis scenario.

First of all, the endogenous liquidation hurdle A^* is affected by the CB borrowing capacity for both banks' type (see Column (1)). In the presence of the CB, the abandonment hurdle A^* increases enlarging the liquidation region. If the bank relies on CB liquidity, rollover losses arise when the bank is in distress. Due to rollover losses, equity holders might then prefer liquidation instead of issuing equity depending on asset shock realisations. The equity value increases in the presence of CB and when the borrowing capacity is larger (see Column (2)). With a tighter CB borrowing capacity, the average CB borrowing over assets implied by the simulation exercise is lower: the borrowing decreases to 0.36% (0.94%) from 1.57% (2.95%) for High (Low)-NSFR type (see Column (3)). Although the average CB borrowing over assets is positive, the median is null suggesting that both bank types do not spend much time in the credit region although they have a large credit line with the CB. As expected, the average and the 90th percentile dramatically increase in the "bad state" scenario, indicating that the bank could become highly reliant on CB liquidity consistent with the pattern we observe in the data (see Figure 1). Due to CB seniority, rollover losses on average increase and their distribution is more fat-tailed when the borrowing capacity is larger, especially in the "bad state" scenario (see Column (4)). Interestingly, the High-NSFR bank can experience larger rollover losses. The reason is the larger liquidation region ($A^* - A^B = 65 - 62$ for High-NSFR bank and $A^* - A^B = 73 - 72$ for Low-NSFR bank) due to the lower *ex ante* exogenous solvency level A^B . The default probability of High-NSFR bank is 3.44% and is lower than for Low-NSFR bank type, 5.39%, because the High-NSFR bank has a larger credit region with the CB (see bottom panel of Figure B.5 of Online Appendix) and smaller total coupon payments amount to be paid.³⁰ However, a larger borrowing capacity does not necessarily imply a lower default probability. For the Low-NSFR bank type the default probability slightly decreases from 5.39% to 5.04% with a tighter borrowing capacity.

Table 7 provides the numerical results for investment (Column (1)), equity issuance (Columns (2) – (3)), and dividends' payment (Column (4) – (5)). Access to CB liquidity improves the bank's investment problem (see Column (1)). In the presence of CB, the average bank's investment is 5.83% (5.81%) for High (Low)-NSFR type which is slightly higher than

³⁰Figure B.5 of Online Appendix plots the dividends' payout boundary (top panel) and the cash after equity issuance and equity issuance boundaries (bottom panel) for High and Low-NSFR bank. The total coupon payments amount, $C^S + C^U + C^D$, is 2.23 (2.61) for High (Low)-NSFR bank.

5.69% (5.70%) when the bank has more limited access to CB liquidity. This model prediction is consistent with the quantitative prediction of Bocola (2016) and De Fiore, Hoerova, and Uhlig (2018) and empirical evidence in Alves, Bonfim, and Soares (2021), Carpinelli and Crosignani (2021) and Jasova, Mendicino, and Supera (2021) who show that access to ECB liquidity supports bank lending.^{31, 32}

As previously discussed, the average bank's investment increases in the "bad state" scenario due to risk taking (see top panel of Figure 6). Equity issuance is less frequent the larger the borrowing capacity is (see Column (2)). As a result, the original owners are diluted down to an average ownership stake of 92.15% (81.80%) with a large borrowing capacity for High(Low)-NSFR bank after 20 years. Thus, the original owners of the High-NSFR type bank benefit more of having access to CB liquidity because ownership is barely affected. With a tighter borrowing capacity, the Low-NSFR bank type's original owners retain a much lower average stake of 77.87%. As expected, the equity dilution is larger in the "bad stress" scenario because equity issuance is mainly triggered when the bank relies on CB liquidity. Finally, the distribution is very skewed because the bank will optimally tap equity markets only intermittently, and, when doing so, it raises funds in lumps, consistent with observed bank behaviour (see Panel C of Table 1). Finally, the dividends' payment is more frequent and the overall dividends' payout is larger in the presence of the CB because the bank has a lower dividend boundary $\bar{W}(A)$ and as result it significantly holds less cash (see Columns (4 – 5)). As expected, dividends' payment is less frequent and the overall dividends' payout is smaller in the "bad state" scenario because the bank on average relies more on CB liquidity and is more far away from the dividend boundary.

Overall, our results shed light on the long-term implications of having a permanent and broad access to CB liquidity. Although having access to CB liquidity substantially mitigates the bank's underinvestment problem in a crisis scenario, keeping the LOLR policies for

³¹Bocola (2016) examines the macroeconomic implications of sovereign risk in a model in which banks hold domestic government debt. He estimates the model using Italian data, finding that sovereign risk was recessionary and that the risk channel was sizable. He uses the model to measure the effects of 3-year LTROs to banks. Precautionary motives imply that bank lending to firms responds little to these interventions. De Fiore, Hoerova, and Uhlig (2018) examine the role of ECB collateral policy when the bank faces frictions in money markets. Their general equilibrium framework shows that when banks face decreasing access to unsecured funding and higher private repo haircuts in secured funding markets, it can lead to moderate output and lending contractions.

³²Alves, Bonfim, and Soares (2021) use the Portuguese Central Credit Register combining this with bank-level data on the recourse to ECB monetary policy operations and standing facilities and the collateral pool. They show that the access to ECB 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. 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.

too long can result in a wealth transfer from creditors to equity holders through increased dividend payments in good states, coupled with more risk-taking and earlier liquidation in bad states.

7 Conclusion

Using novel data sets on banks' asset holdings and ECB eligibility and haircuts criteria, we provide a time-varying estimated of banks' borrowing capacity which measures the bank's ability to draw liquidity at the ECB in the full allotment regime. We also use a novel proprietary dataset on the characteristics of asset and liabilities euro area banks we construct estimates of ex-ante funding profiles of banks.

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 regulatory requirements. Banks manage their liquidity by i) building cash buffers, ii) 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.

We use the data to calibrate the parameters of our model and find the following results. On the positive side, the size of the loan portfolio is higher when the banks have a larger borrowing capacity with CB. 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 banks can be incentivised to pursue more conservative dividend policies.

References

- Acharya, Viral V, Thomas Cooley, Matthew Richardson, Ingo Walter, et al. 2010. "Manufacturing tail risk: A perspective on the financial crisis of 2007–2009." *Foundations and Trends® in Finance* 4 (4): 247–325.
- Acharya, Viral V, Hyun Song Shin, and Tanju Yorulmazer. 2011. "Crisis resolution and bank liquidity." *The Review of Financial Studies* 24 (6): 2166–2205.
- Acharya, Viral V, and Sascha Steffen. 2015. "The "greatest" carry trade ever? Understanding eurozone bank risks." *Journal of Financial Economics* 115 (2): 215–236.

- Altavilla, Carlo, Miguel Boucinha, and José-Luis Peydró. 2018. “Monetary policy and bank profitability in a low interest rate environment.” *Economic Policy* 33 (96): 531–586.
- Altinkilic, Oya, and Robert S Hansen. 2000. “Are there economies of scale in underwriting fees? Evidence of rising external financing costs.” *The Review of Financial Studies* 13 (1): 191–218.
- 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.
- Bai, Jennie, Arvind Krishnamurthy, and Charles-Henri Weymuller. 2018. “Measuring liquidity mismatch in the banking sector.” *The Journal of Finance* 73 (1): 51–93.
- Bindseil, Ulrich. 2013. “Central bank collateral, asset fire sales, regulation and liquidity.” Technical Report, ECB Working Paper.
- Bindseil, Ulrich, Marco Corsi, Benjamin Sahel, and Ad Visser. 2017. “The Eurosystem collateral framework explained.” Technical Report, ECB Occasional Paper.
- Blank, Michael, Samuel G Hanson, Jeremy C Stein, and Adi Sunderam. 2020. “How should US bank regulators respond to the COVID-19 crisis?” *Hutchins Center on Fiscal and Monetary Policy at Brookings, Hutchins Center Working Paper*, vol. 63.
- 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.
- . 2013. “Market timing, investment, and risk management.” *Journal of Financial Economics* 109 (1): 40–62.
- . 2014. “Debt, taxes, and liquidity.” Technical Report, National Bureau of Economic Research.
- Bolton, Patrick, Ye Li, Neng Wang, and Jinqiang Yang. 2023. “Dynamic banking and the value of deposits.” Technical Report, forthcoming in *Journal of Finance*.
- 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.
- Constâncio, Vítor. 2014. “Recent challenges to monetary policy in the euro area.” *Monetary Policy, Banking Union and Economic Growth*, p. 19.

- 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. 2018. “Money markets, collateral and monetary policy.” Technical Report, National Bureau of Economic Research.
- Della Seta, Marco, Erwan Morellec, and Francesca Zucchi. 2020. “Short-term debt and incentives for risk-taking.” *Journal of Financial Economics* 137 (1): 179–203.
- 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.
- Diamond, Douglas W, and Raghuram G Rajan. 2011. “Fear of fire sales, illiquidity seeking, and credit freezes.” *The Quarterly Journal of Economics* 126 (2): 557–591.
- 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.
- Drechsler, Itamar, Alexi Savov, and Philipp Schnabl. 2021. “Banking on deposits: Maturity transformation without interest rate risk.” *The Journal of Finance* 76 (3): 1091–1143.
- Farhi, Emmanuel, and Jean Tirole. 2012. “Collective moral hazard, maturity mismatch, and systemic bailouts.” *American Economic Review* 102 (1): 60–93.
- 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. 2012. “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.
- Huang, Jing-Zhi, and Ming Huang. 2012. “How much of the corporate-treasury yield spread is due to credit risk?” *The Review of Asset Pricing Studies* 2 (2): 153–202.

- Hugonnier, Julien, Semyon Malamud, and Erwan Morellec. 2015. “Capital supply uncertainty, cash holdings, and investment.” *The Review of Financial Studies* 28 (2): 391–445.
- Hugonnier, Julien, and Erwan Morellec. 2017. “Bank capital, liquid reserves, and insolvency risk.” *Journal of Financial Economics* 125 (2): 266–285.
- Jasova, Martina, Luc Laeven, Caterina Mendicino, José-Luis Peydró, and Dominik Supera. 2023. “Systemic risk and monetary policy: The haircut gap channel of the lender of last resort.” *The Review of Financial Studies*, p. hhad100.
- 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.
- Jermann, Urban, and Haotian Xiang. 2023. “Dynamic banking with non-maturing deposits.” *Journal of Economic Theory* 209:105644.
- 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.
- 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.
- Praet, Peter. 2016. “The ECB and its role as lender of last resort during the crisis (Speech at the Committee on Capital Markets Regulation conference on the lender of last resort—an international perspective).” *Washington DC*, vol. 10.
- Puriya, Abbassi, Rajkamal Iyer, José-Luis Peydró, and Francesc Tous. 2016. “Securities trading by banks and credit supply: Micro-evidence.” *Journal of Financial Economics* 121 (3): 569–594.
- Repullo, Rafael. 2018. “Liquidity, Risk Taking, and the Lender of Last Resort-IJCB-September 2005.” *Second issue (September 2005) of the International Journal of Central Banking*.

- Rochet, Jean-Charles, and Xavier Vives. 2004. “Coordination failures and the lender of last resort: Was Bagehot right after all?” *Journal of the European Economic Association* 2 (6): 1116–1147.
- Santos, Joao AC, and Javier Suarez. 2019. “Liquidity standards and the value of an informed lender of last resort.” *Journal of Financial Economics* 132 (2): 351–368.
- Schnabel, Isabel. 2023. “Back to normal? Balance sheet size and interest rate control.” *Speech given at an event organised by Columbia University and SGH Macro Advisors, New York.*
- 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.
- Subramanian, Ajay, and Baozhong Yang. 2020. “Dynamic prudential regulation.” *Management Science* 66 (7): 3183–3210.
- Sundaresan, Suresh, and Kairong Xiao. 2024. “Liquidity regulation and banks: theory and evidence.” *Journal of Financial Economics* 151:103747.

Tables

Table 1: **Summary statistics** - This table provides bank-level summary statistics from July 2007 to March 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 (annual frequency)						
Equity issuance (yes = 1)	0.13	0.33	0.00	0.00	1.00	724
Equity issuance / equity (%)	15.96	12.10	3.56	12.03	35.81	91
Dividends payment (yes = 1)	0.40	0.49	0.00	0.00	1.00	744
Dividends pay / equity (%)	1.93	3.90	0.00	0.00	6.53	744
D - Funding profile						
NSFR (%)	96.44	39.95	59.16	91.59	130.82	18,321
E - Borrowing capacity						
Borrowing capacity / assets (%)	27.52	15.04	8.50	26.21	46.95	14,775
Borrowing capacity sec. / assets (%)	12.96	9.71	0.095	11.92	25.35	14,547

Table 2: **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)	(2)	(3)	(4)	(5)	(6)	(7)
	All banks			Banks participating ECB operations			
	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq. + 1)	Log (Liq.)	Log (Liq.)
NSFR	-0.003***	-0.023***	-0.031***	-0.032***	-0.034***	-0.015***	-0.018***
Borrowing capacity	0.055***	0.082***	0.110***	0.087	-0.031***	0.049***	-0.013***
Rating			0.165*	0.604***	-0.029***	0.060*	-0.011***
NSFR x Post Lehman					0.115***		0.032**
NSFR x Post Greek					0.085**		0.051***
NSFR x Post 3y LTRO					0.129***		0.077***
Borr. capacity x Post Lehman					-0.038		-0.077
Borr. capacity x Post Greek					0.228**		0.084**
Borr. capacity x Post 3y LTRO					0.113		0.056
Assets (log)	0.875***	2.318***	2.752***	2.465*	2.702***	2.453***	2.531***
Capital ratio	0.076***	0.055	0.111**	0.052	0.105**	0.061**	0.076***
Obs.	14,350	14,350	5,482	2,999	5,482	2,528	2,528
R-squared	0.168	0.656	0.659	0.550	0.665	0.820	0.828
Bank FE		Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3: **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 the amount borrowed from the ECB in natural logarithmic including (Columns (1) – (2)) and excluding observations with zero ECB borrowing (Columns (3) – (4)). 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) – (4) 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)	(2)	(3)	(4)
	All banks		Banks participating ECB operations	
	Log (Borr. + 1)	Log (Borr. + 1)	Log (Borr.)	Log (Borr.)
NSFR 2007 x Post Lehman	-0.011*	-0.034***	-0.017***	-0.024***
NSFR 2007 x Post Greek	0.003	-0.008	-0.012**	-0.029***
NSFR 2007 x Post 3y LTRO	0.007	-0.006	0.001	-0.010
Rating 2007 x Post Lehman	0.073	-0.040	-0.057	-0.077
Rating 2007 x Post Greek	0.165**	0.175**	-0.007	0.064
Rating 2007 x Post 3y LTRO	0.104	0.210***	0.038	0.061
Assets 2007 (log)	0.960***	0.291**	0.687***	0.650***
Capital ratio 2007	0.005	-0.004	0.015	0.018
Obs.	11,067	6,045	4,871	2,310
R-squared	0.392	0.374	0.654	0.549
Time x Country FE	Y	Y	Y	Y

Table 4: **Balance sheet characteristics of Low vs High-NSFR banks** - This table compares the characteristics of banks with low NSFR and high NSFR as of August 2007. The asset and liability 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.

	Low-NSFR		High-NSFR		t-test
	Mean	Std.dev.	Mean	Std.dev.	
	$N = 63$		$N = 64$		
Panel A					
Assets	47,845	66,282	31,231	50,551	1.59
D. non-distressed sovereign	0.59	0.50	0.63	0.49	-0.43
Panel B - Asset					
Cash and deposits CB ($w = 0$)	0.50	0.76	0.75	1.06	-1.49
Government debt ($w = 0.05$)	2.39	3.88	9.85	14.54	-3.96
MFI loans and corporate debt ($w = 0.15$)	15.95	13.23	22.43	18.12	-2.24
Loans $< 1y$ ($w = 0.5$)	9.14	8.41	13.08	11.43	-2.22
Household mortgages $> 1y$ ($w = 0.65$)	6.86	7.16	4.80	4.82	1.87
Household, NFC Loans $> 1y$ & Equity ($w = 0.85$)	34.11	23.27	30.15	20.01	1.01
Other ($w = 1$)					
- MFI and other debt	7.52	10.75	7.90	8.85	-0.21
- MFI and other equity	1.04	2.43	1.40	2.22	-0.87
- Loans to OFI	16.59	24.00	8.93	11.65	2.27
- Other assets	4.69	7.21	2.91	2.79	1.81
Panel C - Liability					
Debt $< 1y$, Repo and MFI dep. ($w = 0$)	36.01	20.82	12.47	10.25	8.06
NFC overnight and govern. dep. ($w = 0.5$)	9.34	10.02	9.62	10.70	-0.15
NFC dep. $> 3month$ ($w = 0.9$)	8.06	8.09	17.66	14.76	-4.41
Households dep. $< 1y$ ($w = 0.95$)	12.76	11.04	31.87	24.10	-5.76
Other ($w = 1$)					
- Households dep. $> 1y$	1.58	5.32	2.46	5.63	-0.88
- NFC dep. $> 1y$	0.31	0.55	0.19	0.41	1.38
- Debt $> 1y$	11.92	11.51	15.20	20.05	-1.10
- Equity	5.98	5.85	9.50	9.98	-2.43
	$N = 41$		$N = 45$		
Panel D - Rates					
New loans households	5.84	0.68	5.80	1.03	0.21
New loans NFC	5.39	0.42	5.47	0.75	-0.60
New deposits households	3.78	0.69	3.73	0.80	0.31
New deposits NFC	4.15	0.31	4.04	0.58	1.09

Table 5: **Parameters**

Variable	Symbol	Low-NSFR	High-NSFR	Source
Panel A				
<i>Balance sheet</i>				
Cash - Safe asset	W_0	1	1	IBSI
Asset portfolio	A_0	99	99	IBSI
Stable deposits	P_0^S	28	37	IBSI
Unstable deposits	P_0^U	54	39	IBSI
Debt	P_0^D	12	15	IBSI
Equity	E_0	6	9	IBSI
Solvency	A^B	71	62	
Panel B				
<i>Central bank</i>				
Risk-free rate	r		2.23%	ECB
Penalty spread	s^{CB}		0.50%	ECB
Borrowing capacity	$1 - \Theta$			Estimate
- Securities		11.96%	12.84%	
- Securities and loans		29.56%	32.68%	
<i>Assets</i>				
Loans' maturity (years)	δ	10.96	10.09	IBSI
Volatility of asset-shock	σ^X	9.29%	9.21%	IBSI & Estimate
Risk premium	$\tilde{\mu}^X$	3.2%	3.4%	Estimate
Jump intensity	η^X		2.5%	Estimate
Jump size	ξ^X		-20%	Estimate
Carry cost of cash	λ		1%	Literature
Unit price for loan investment			5%	Estimate
<i>Liabilities</i>				
Coupon stable funding	C^S	0.62	0.82	
Unstable funding maturity (years)	m^U	0.21	0.17	IBSI & CSDB
Unstable funding spread	s^U	0.77%	0.16%	IBSI & CSDB
Coupon unstable funding	C^U	1.62	0.94	
Debt maturity (years)	m^D	3.37	3.01	IBSI & CSDB
Debt coupon spread	s^D	0.86%	0.95%	IBSI & CSDB
Coupon debt	C^D	0.37	0.48	
Fixed equity issuance cost	ϕ		2	Literature
Proportional equity issuance cost	γ		5.5%	Literature
Proportional liquidation	l	0.72	0.9	Estimate

Table 6: **CB borrowing capacity and funding structure: CB borrowing, rollover losses and default** - Columns (1) – (2) are based on the model solution. Column (2) reports the equity value at (W_0, A_0) . Columns (3) – (5) report the statistics of model panel data based on 25,000 simulations with a 20-year horizon (daily frequency). Columns (3) – (4) report the mean and the 10th, 50th and 90th percentiles in brackets for the simulated variables. For Columns (3) – (4) the statistics are also reported for the crisis scenario. The crisis scenario is defined by selecting state variables at which return on asset computed on A_t falls below its 5th percentile.

	(1)	(2)	(3)	(4)	(5)
Θ	Liquidation hurdle	Equity value	CB borrowing over assets (%)	Rollover losses	Default probability (%)
High-NSFR					
32.68%	65.00	69.56	1.57 [0,0,6.20] 3.14 [0, 0, 11.76]	-0.98 [-2.37,-0.69,-0.01] -1.48 [-3.00,-1.22,-0.21]	3.44
12.84%	64.00	62.73	0.36 [0,0,0] 0.82 [0, 0, 3.64]	-0.46 [-1.05,-0.37,-0.01] -0.80 [-1.52,-0.69,-0.23]	4.28
Low-NSFR					
29.56%	73.00	55.52	2.95 [0,0,11.01] 4.51 [0,0.91,14.51]	-0.65 [-1.43,-0.51,-0.01] -1.09 [-2.15,-0.92,-0.17]	5.39
11.96%	72.00	49.64	0.94 [0,0,4.06] 1.46 [0,0,6.10]	-0.21 [-0.53,-0.04,0] -0.36 [-0.82,-0.17,-0.02]	5.04

Table 7: **CB borrowing capacity and funding structure: Investment, equity dilution and dividends' payment** - Columns (1) – (5) report the statistics of model panel data based on 25,000 simulations with a 20–year horizon (daily frequency). Columns (1), (3) and (5) report the mean and the 10th, 50th and 90th percentiles in brackets for the simulated variables. The statistics are also reported for the crisis scenario. The crisis scenario is defined by selecting state variables at which return on asset computed on A_t falls below its 5th percentile.

	(1)	(2)	(3)	(4)	(5)
Θ	Investment	Dummy equity issuance (%)	Original ownership equity (%)	Dummy dividends payment (%)	Dividends' payout
High-NSFR					
32.68%	5.83 [4.30,5.46,7.78] 7.10 [5.10,6.47,9.82]	1.01 2.29	92.15 [100,100,100] 84.45 [8.35,100,100]	21.31 0.08	36.01 [5.97,29.80,76.87] 7.85 [2.33,5.26,21.21]
12.84%	5.69 [4.36,5.19,7.60] 6.83 [4.79,6.20,9.58]	1.13 1.86	90.56 [25.48,100,100] 84.81 [6.42,100,100]	9.66 0.01	28.88 [4.63,23.88,61.09] 25.58 [25.58,25.58,25.58]
Low-NSFR					
29.56%	5.81 [4.01,5.31,8.10] 6.92 [4.73,6.36,9.72]	2.05 3.72	81.80 [8.89,100,100] 72.27 [6.91,100,100]	19.60 0	14.54 [1.03,6.89,41.42] 3.58 [3.58,3.58,3.58]
11.96%	5.70 [4.08,5.11,7.93] 6.74 [4.52,6.09,9.63]	2.43 3.70	77.87 [7.95,100,100] 69.83 [6.38,100,100]	6.31 0.07	18.65 [0.81,6.45,46.68] 4.34 [0.19,3.65,9.22]

Figures

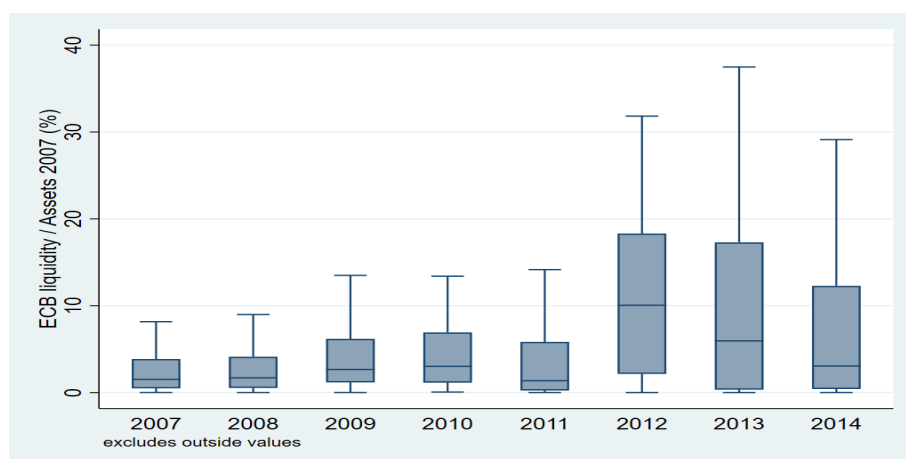


Figure 1: **Banks' reliance on ECB liquidity** - The figure plots the ECB liquidity over assets 2007 distribution for banks who rely on ECB liquidity in our sample for the period 2007 to 2014. The figure draws a box ranging from the first to the third quartile with a line at the median. The "whiskers" going from the box to the adjacent values are the highest and lowest values that are not farther from the median than 1.5 times the interquartile range.

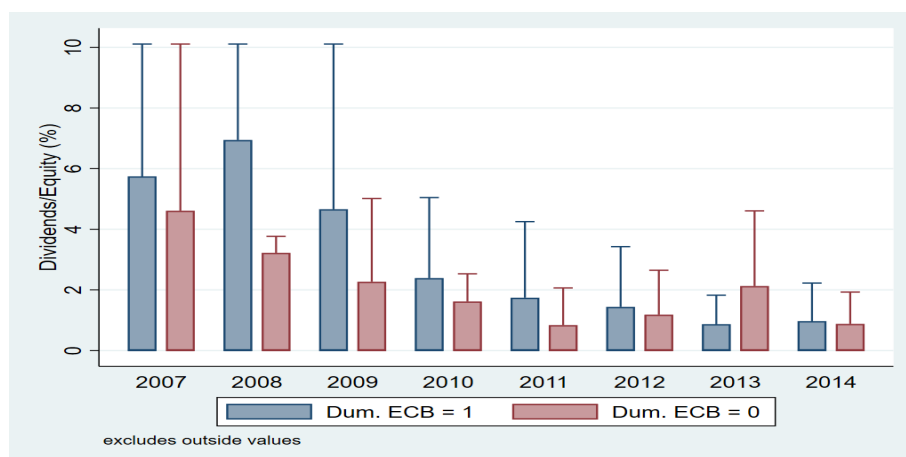


Figure 2: **Banks' dividends** - The figure plots the dividends payout over equity distribution for banks who rely and do not rely on ECB liquidity in our sample for the period 2007 to 2014. The figure draws a box ranging from the first to the third quartile with a line at the median. The "whiskers" going from the box to the adjacent values are the highest and lowest values that are not farther from the median than 1.5 times the interquartile range.

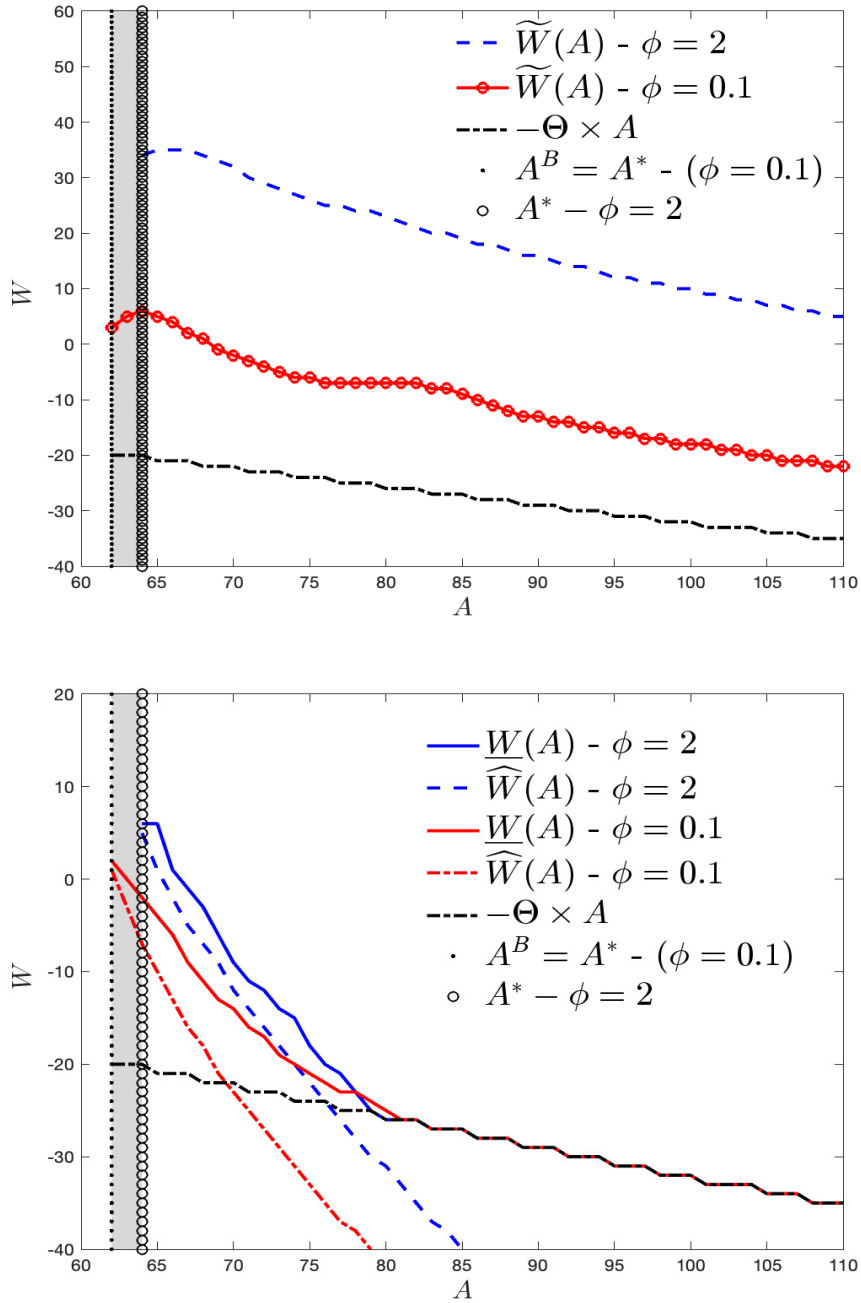


Figure 3: **Fixed cost of issuing equity** - The figure plots the model solution for the High-NSFR type bank. The parameters are reported in Table 5. The top panel plots the cash level after issuing equity boundary $\widetilde{W}(A)$ and the liquidation hurdle A^* for $\phi = 2$ and $\phi = 0.1$. The bottom panel plots the equity issuance boundary $\underline{W}(A)$, the liquidation boundary $\widetilde{W}(A)$ and the liquidation hurdle A^* for $\phi = 2$ and $\phi = 0.1$.

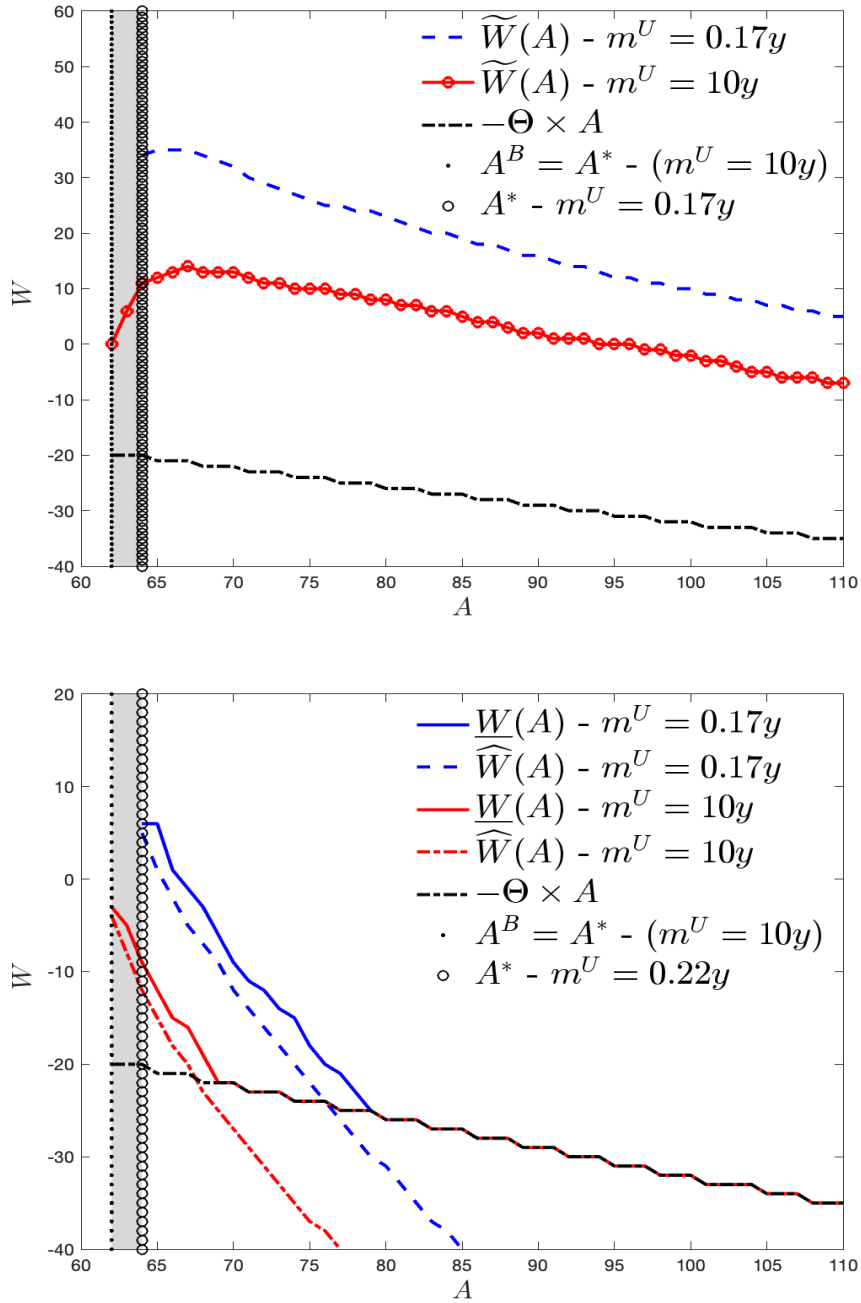


Figure 4: **Unstable deposits' maturity** - The figure plots the model solution for the High-NSFR type bank. The parameters are reported in Table 5. The top panel plots the cash level after issuing equity boundary $\widetilde{W}(A)$ and the liquidation hurdle A^* for $m^U = 0.17$ and $m^U = 10$ years. The bottom panel plots the equity issuance boundary $\underline{W}(A)$, the liquidation boundary $\widehat{W}(A)$ and the liquidation hurdle A^* for $m^U = 0.17$ and $m^U = 10$ years.

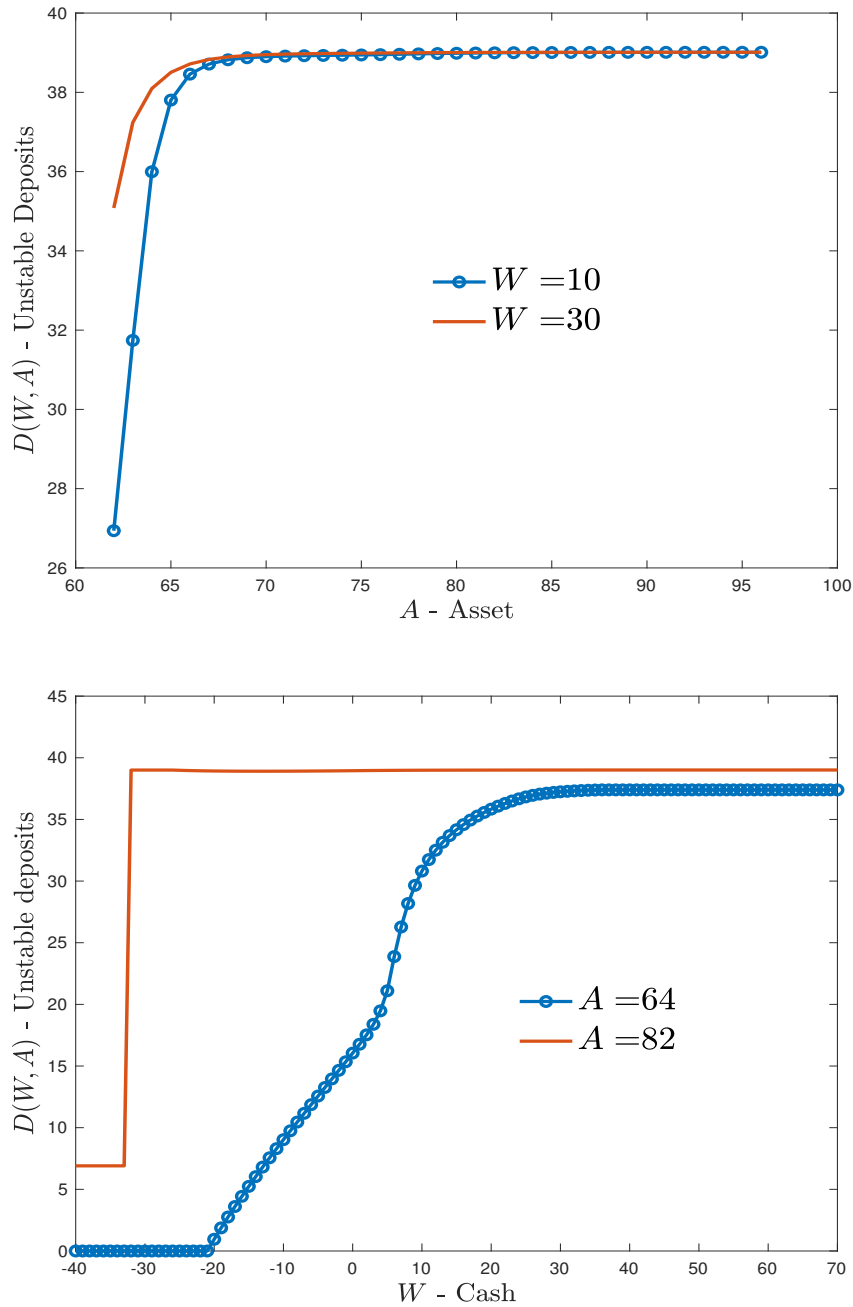


Figure 5: **Market value of unstable deposits'** - The figure plots the market value of unstable deposits' for the High-NSFR type bank. The parameters are reported in Table 5. The top panel plots $D(W, A)$ against A for $W = 10$ and $W = 30$. The bottom panel plots $D(W, A)$ against W for $A = 64$ and $W = 82$.

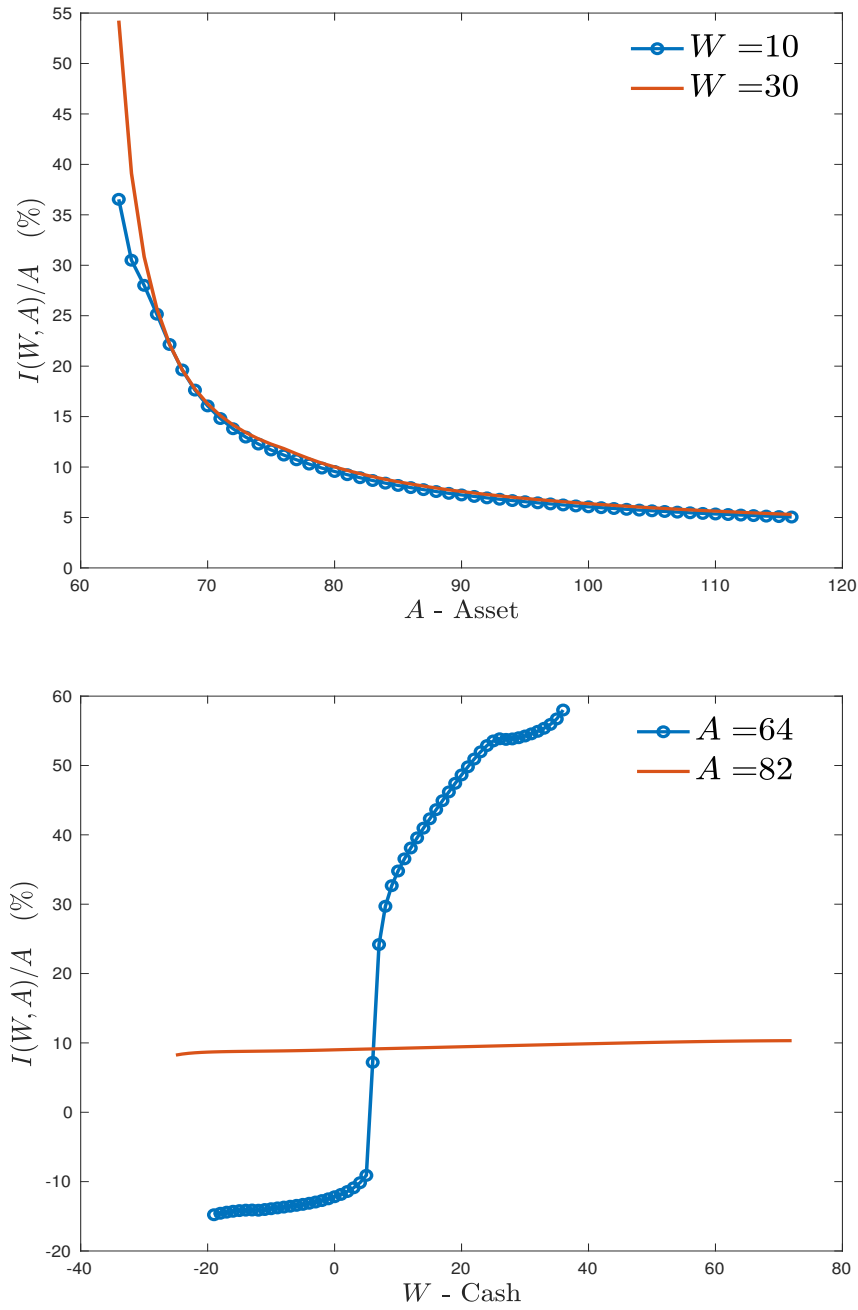


Figure 6: **Investment** - The figure plots the investment policy for the High-NSFR type bank. The parameters are reported in Table 5. The top panel plots $I(W, A)/A$ against A for $W = 10$ and $W = 30$. The bottom panel plots $I(W, A)/A$ against W for $A = 64$ and $W = 82$.

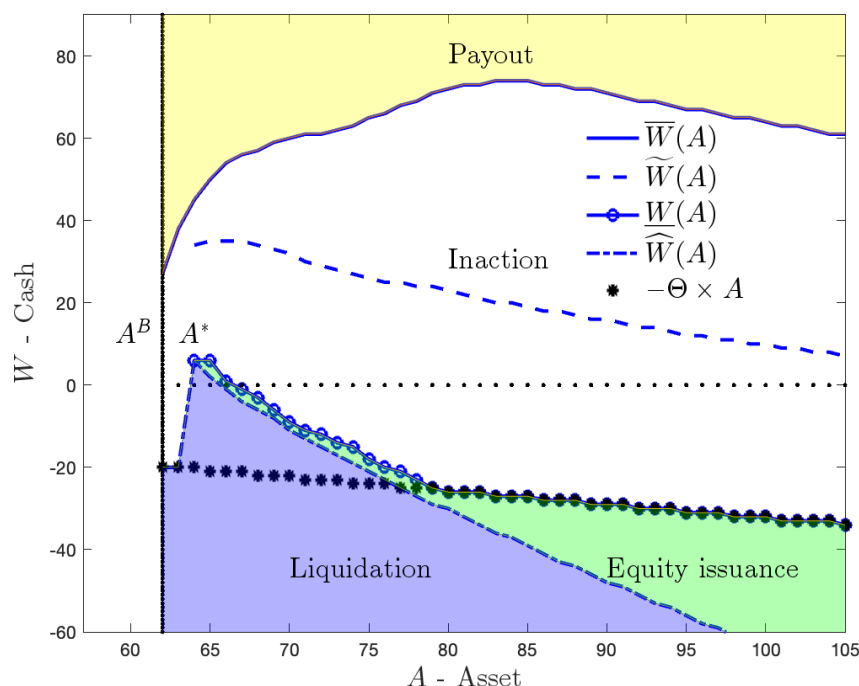


Figure 7: **Model solution** - The figure plots the model solution for the High-NSFR type bank. The parameters are reported in Table 5.

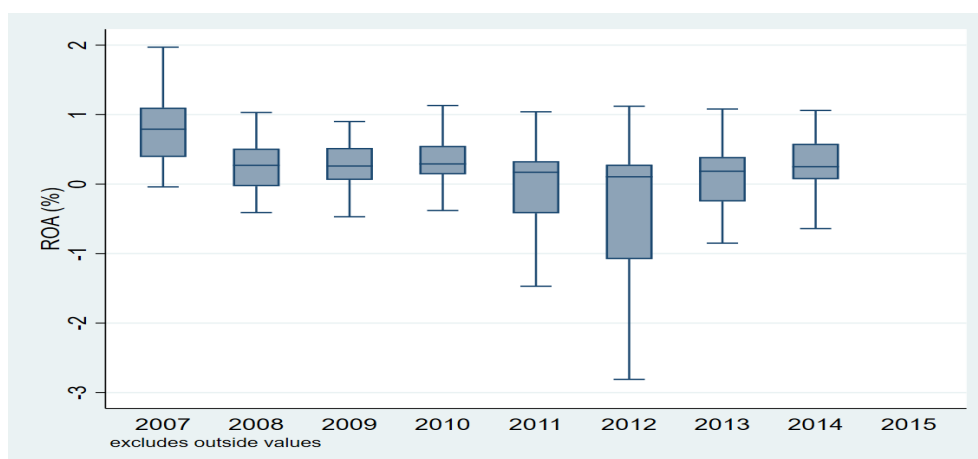
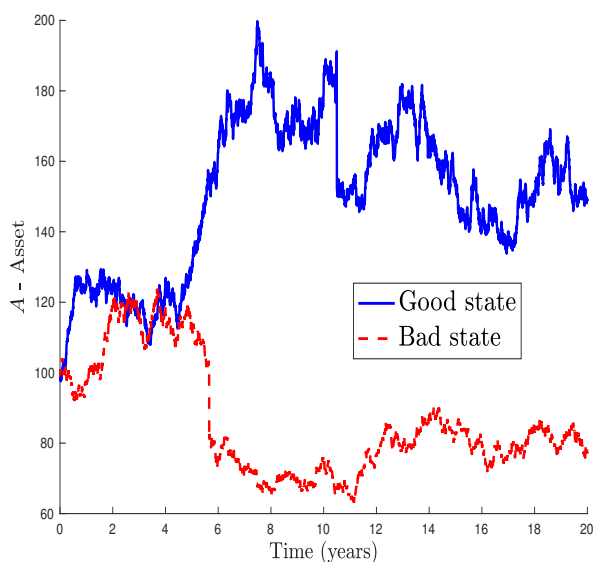
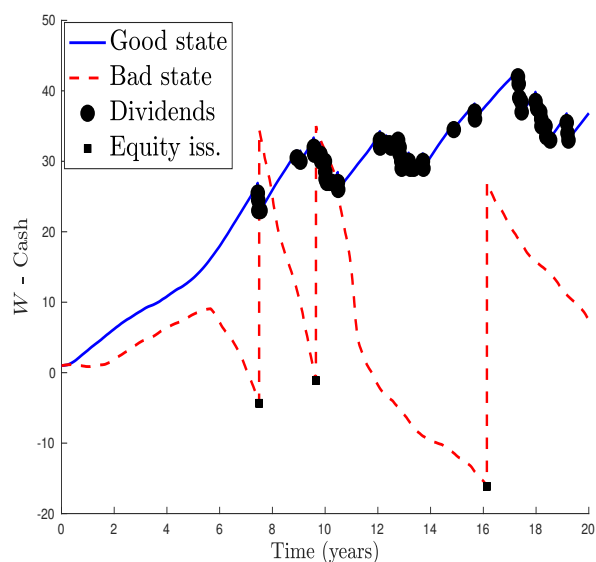


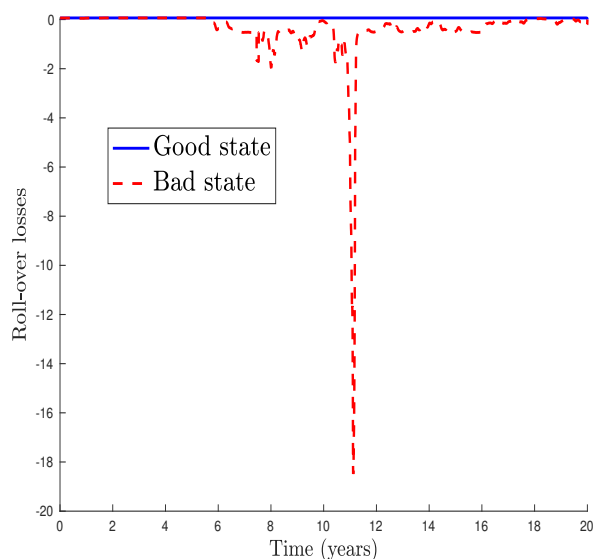
Figure 8: **Banks' return on assets** - The figure plots the distribution of the return on assets for banks in our sample for the period 2007 to 2014. The figure draws a box ranging from the first to the third quartile with a line at the median. The "whiskers" going from the box to the adjacent values are the highest and lowest values that are not farther from the median than 1.5 times the interquartile range.



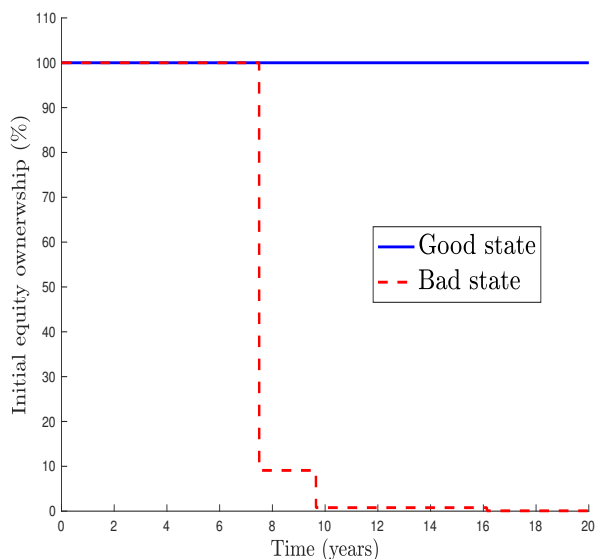
(a) Asset



(b) Cash



(c) Rollover losses



(d) Equity dilution

Figure 9: **Asset, cash accumulation, rollover losses and equity dilution for two simulated paths** - The blue line plots the "good state" scenario where the bank pays dividends after accumulating cash (● indicates where the dividends are paid). The red dotted line plots the "bad state" scenario where the bank issues equity two times when cash flow shocks deplete the liquidity the bank can borrow from the CB (■ indicates where the bank raises equity). The "bad state" scenario is defined by selecting state variables at which return on asset computed on A_t falls below its 5th percentile. All the variables are initialised at (W_0, A_0) .

Appendix

A-I 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.¹ 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

¹See <https://www.ecb.europa.eu/paym/coll/assets/html/index.en.html>.

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-I 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 DBRS 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-I 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.

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 10th and 90th percentile of the fraction of eligible marketable securities for each asset category. Columns (4)-(6) provides the mean, the 10th and 90th 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.

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.² 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-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

²Syndicated loans are also in principle accepted as collateral, but their use so far has been limited.

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 $\widetilde{NMA}_{j,is,ia,t}$ 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 plots the mean, the 10th and 90th 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%.

Finally, 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.

We also provide a formal empirical analysis of the banks' borrowing capacity. Results reported in Table A-II indicate 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 of marketable securities. Additionally, we observe that the rating coefficient is not statistically significant suggesting that that riskier banks do not necessarily have a larger borrowing capacity to rely on ECB liquidity.

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

IBSI categories	ECB Eligible Share			ECB Haircut Θ		
	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

Table A-II: **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. All columns include bank and country x month time fixed effects. Standard errors in parentheses are double-clustered at the bank and country x month levels. *** Significant at the 1% level, ** significant at the 5% level, and *significant at the 10% level.

	(1)	(2)	(3)	(4)
	Borrowing Capacity	Borrowing Capacity	Borrowing Capacity Securities	Borrowing Capacity Securities
Holdings mark sec.	0.498***	0.460***	0.597***	0.575***
ECB elig. & haircuts	-0.095***	-0.122***	-0.114***	-0.124***
Rating		0.172		0.039
Assets (log)	-0.631	-1.929	-0.025	-0.092
Capital ratio	-0.111	-0.143	-0.109**	-0.154***
Obs.	13,263	5,240	13,263	5,240
R-squared	0.9487	0.9616	0.9619	0.9721
Bank FE	Yes	Yes	Yes	Yes
Time x Country FE	Yes	Yes	Yes	Yes

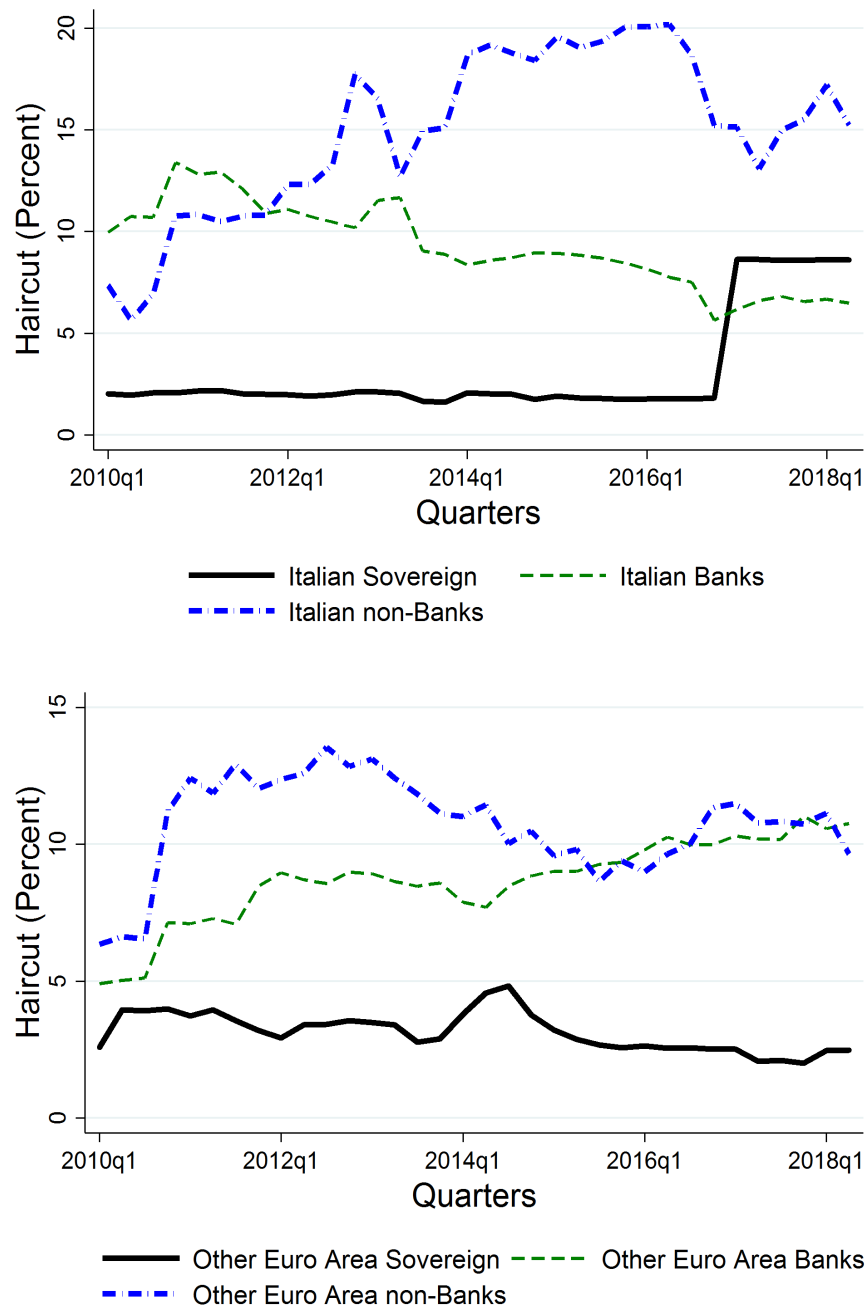


Figure A-I: ECB haircut for the Italian Banking Sector - $\theta_{hc,is,ia,t}$

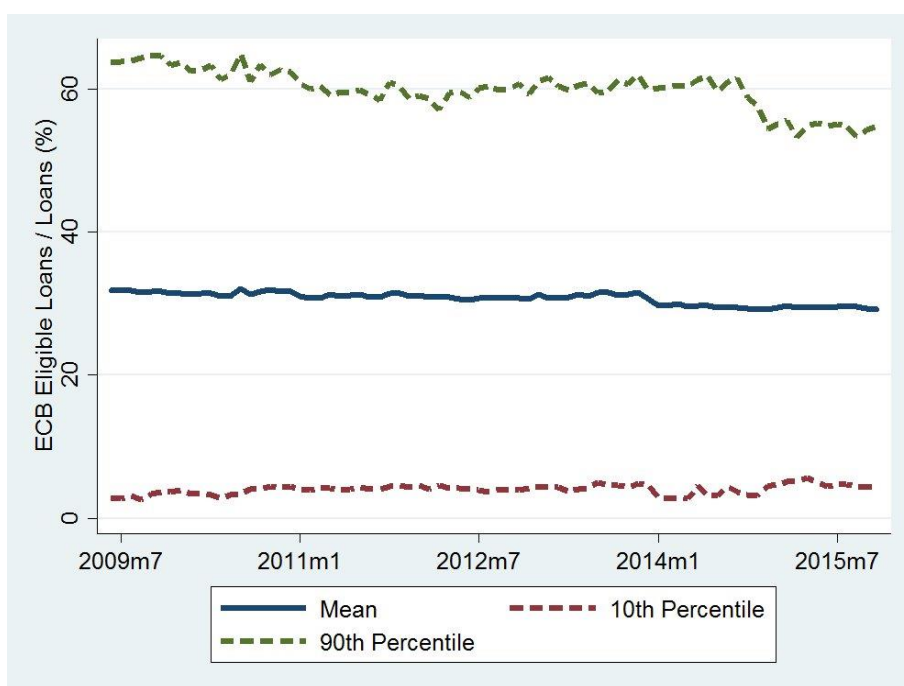


Figure A-II: Non-marketable assets (loans) - $\widetilde{NMA}_{j,t} / \text{Total Loans}_{j,t}$

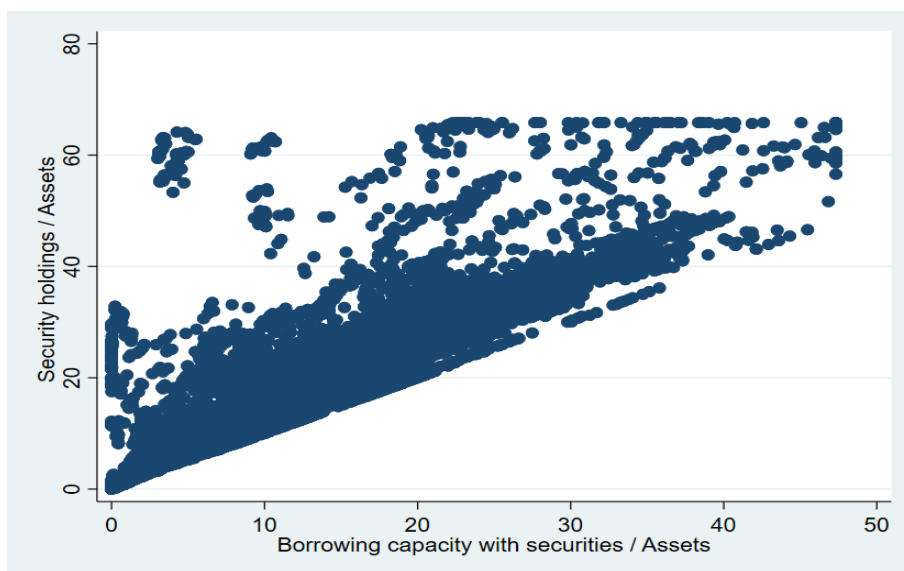


Figure A-III: Fixed income security holdings and borrowing capacity with fixed income securities

A-II Model solution

A-II.1 Equity

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.

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 regulatory requirements.

1. Payout Region: $\bar{W}(A) < W$

Let $\bar{W}(A)$ 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 $\bar{W}(A)$. Moreover, bank's equity value must be continuous before and after cash distribution. Therefore, for $W(A) > \bar{W}(A)$, we have the following equation for $E(W, A)$:

$$E(W, A) = \underbrace{(W(A) - \bar{W}(A))}_{\text{Cash distribution}} + E(\bar{W}(A), A) \quad \text{if } W(A) > \bar{W}(A). \quad (\text{A-1})$$

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

$$E_W(\bar{W}(A), A) = 1. \quad (\text{A-2})$$

2. Internal Financing Region: $\bar{W}(A) > W \geq \max(0, \underline{W}(A))$

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

$$\begin{aligned} rE = & \left((r - \lambda)W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D}(D(W, A; m^D, s^D) - P^D) \right. \\ & \left. - C^U + \frac{1}{m^U}(D(W, A; m^U, s^U) - P^U) \right) E_W \\ & + \left((r + \tilde{\mu}^X)A + I^* - \frac{A}{\delta} \right) E_A + \frac{(\sigma^X A)^2}{2} E_{AA} + \eta^X [E(W, A - \xi^X A) - E], \end{aligned} \quad (\text{A-3})$$

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

$$I_t = \frac{1}{2\psi} \left(\frac{E_A(W, A)}{E_W(W, A)} - 1 \right) \quad (\text{A-4})$$

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: $\max(-\Theta \times A, \underline{W}(A)) \leq W < 0$

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

$$\begin{aligned} rE = & \left((r + s^{CB})W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D}(D(W, A; m^D, s^D) - P^D) \right. \\ & \left. - C^U + \frac{1}{m^U}(D(W, A; m^U, s^U) - P^U) \right) E_W \\ & + \left((r + \tilde{\mu}^X)A + I^* - \frac{A}{\delta} \right) E_A + \frac{(\sigma^X A)^2}{2} E_{AA} + \eta^X [E(W, A - \xi^X A) - E], \end{aligned} \quad (\text{A-5})$$

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-4).

4. Refinancing

When liquidation is not optimal the bank incurs a fixed cost ϕ and a cost γ proportional to the amount of equity raised. Equity value is continuous before and after equity issuance which implies the following condition:

$$E(\underline{W}(A), A) = E(\widetilde{W}(A), A) - \underbrace{\phi}_{\text{Fixed cost}} - (1 + \underbrace{\gamma}_{\text{Marginal cost}}) \times (\widetilde{W}(A) - \underline{W}(A)), \quad (\text{A-6})$$

where $\underline{W}(A)$ is the equity issuance boundary and $\widetilde{W}(A) - \underline{W}(A)$ 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:

$$E_W(\widetilde{W}(A), A) = 1 + \gamma. \quad (\text{A-7})$$

5. Liquidation

The payoff shareholders receive if they liquidate the bank is

$$E(\widehat{W}(A), A) = \max(l \times A + \max(-W, -\Theta \times A) \mathbf{1}_{W < 0} - P^D - P^U - P^S, 0). \quad (\text{A-8})$$

We distinguish here between two cases. First, when $A < A^*$ the shareholders prefer liquidation instead of issuing equity. Therefore, the liquidation boundary $\widehat{W}(A)$ coincides with the

borrowing capacity $-\Theta \times A$. Second, in the equity issuance region, $A \geq A^*$, it is optimal for equity holders to liquidate the bank when issuing equity results in negative equity value. We assume here that the amount of funding the bank is borrowing from the CB at liquidation (or the maximum credit line with CB) has to be paid in full before equity holders can collect any liquidation proceeds as in Bolton, Chen, and Wang (2014) and Della Seta, Morellec, and Zucchi (2020).

6. Insolvency (bank violating regulatory requirements)

We assume that the bank's bankruptcy is triggered when $A \leq A^B$. The payoff shareholders receive is

$$E(W, A) = \max(l \times A + \max(-W, -\Theta \times A) \mathbf{1}_{W < 0} - P^D - P^U - P^S, 0). \quad (\text{A-9})$$

A-II.2 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: $\bar{W}(A) < W$

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

$$D_W(W, A; m^D, s^D) = 0. \quad (\text{A-10})$$

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

2. Internal Financing Region: $\bar{W}(A) > W \geq \max(0, \underline{W}(A))$

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

$$\begin{aligned} \left(r + \frac{1}{m^D}\right) D &= C^D + \frac{1}{m^D} \times P^D \\ &+ \left((r - \lambda)W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D} (D(W, A; m^D, s^D) - P^D) \right. \\ &\quad \left. - C^U + \frac{1}{m^U} (D(W, A; m^U, s^U) - P^U) \right) D_W \\ &+ \left((r + \tilde{\mu}^X)A + I^* - \frac{A}{\delta} \right) D_A + \frac{(\sigma^X A)^2}{2} D_{AA} \\ &+ \eta^X [D(W, A - \xi^X A; m^U, s^U) - D], \end{aligned} \quad (\text{A-11})$$

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

3. CB Funding Region: $\max(-\Theta \times A, \underline{W}(A)) \leq W < 0$

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

$$\begin{aligned}
\left(r + \frac{1}{m^D}\right) D &= C^D + \frac{1}{m^D} \times P^D \\
&+ \left((r + s^{CB})W + \frac{A}{\delta} - I^* - g(I^*) - C^S - C^D + \frac{1}{m^D} (D(W, A; m^D, s^D) - P^D) \right. \\
&\quad \left. - C^U + \frac{1}{m^U} (D(W, A; m^U, s^U) - P^U) \right) D_W \\
&+ \left((r + \tilde{\mu}^X)A + I^* - \frac{A}{\delta} \right) D_A + \frac{(\sigma^X A)^2}{2} D_{AA} \\
&+ \eta^X [D(W, A - \xi^X A; m^U, s^U) - D].
\end{aligned} \tag{A-12}$$

4. Refinancing

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

$$D(\underline{W}(A), A; m^D, s^D) = D(\widetilde{W}(A), A; m^D, s^D). \tag{A-13}$$

5. Liquidation

If shareholders liquidate the bank, the payoff for bondholders is

$$\text{Payoff} = \max(l \times A + W \mathbf{1}_{W \geq 0} + \max(-W, -\Theta \times A) \mathbf{1}_{W < 0} - P^S, 0). \tag{A-14}$$

Condition (A-14) 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 6.1) 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 . We assume here *pari passu*

$$\Omega = \frac{\text{Payoff}}{P^D + P^U}. \tag{A-15}$$

Therefore, the final payoff for the two bondholder types is

$$D(\widehat{W}(A), A; m^D, s^D) = \min(\Omega \times P^D, P^D), \tag{A-16}$$

$$M(\widehat{W}(A), A; m^U, s^U) = \min(\Omega \times P^U, P^U). \tag{A-17}$$

6. Insolvency (bank violating regulatory requirements)

When the bank's bankruptcy is triggered, the payoff for bondholders is

$$\text{Payoff} = \max(l \times A + W \mathbf{1}_{W \geq 0} + \max(-W, -\Theta \times A) \mathbf{1}_{W < 0} - P^S, 0).$$

The final payoff for the two bondholder types is

$$\begin{aligned} D(W, A; m^D, s^D) &= \min(\Omega \times P^D, P^D), \\ M(W, A; m^U, s^U) &= \min(\Omega \times P^U, P^U). \end{aligned}$$

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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

© European Central Bank, 2024

Postal address 60640 Frankfurt am Main, Germany

Telephone +49 69 1344 0

Website www.ecb.europa.eu

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