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Abstract

We show that lender of the last resort (LOLR) policy contributes to higher bank interconnectedness and associated systemic risk. Using novel micro-level data, we analyze the haircut gap channel of LOLR--the difference between the private market and central bank haircuts. LOLR increases interconnectedness by incentivizing banks to pledge higher haircut gap bonds, especially issued by similar banks and by systemically important banks. LOLR also exacerbates cross-pledging of bank bonds. Higher haircut gaps only incentivize banks, not other intermediaries without LOLR access, to increase bank bond holdings. Finally, LOLR revives bank bond issuance associated with higher haircut gaps.

JEL Classification: E44, E52, E58, F30, G01, G21

Keywords: Central Bank Liquidity, haircuts, Collateral, Bank Risk Concentration, systemic risk

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Systemic Risk and Monetary Policy: The Haircut Gap Channel of the Lender of Last Resort*

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May 2021

Abstract

We show that lender of the last resort (LOLR) policy contributes to higher bank interconnectedness and systemic risk. Using novel micro-level data, we analyze the haircut gap channel of LOLR – the difference between the private market and central bank haircuts. LOLR increases interconnectedness by incentivizing banks to pledge higher haircut gap bonds, especially issued by similar banks and by systemically important banks. LOLR also exacerbates cross-pledging of bank bonds. Higher haircut gaps only incentivize banks, not other intermediaries without LOLR access, to increase bank bond holdings. Finally, LOLR revives bank bond issuance associated with higher haircut gaps.

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In the aftermath of the Global Financial Crisis, central banks expanded their liquidity provision to ensure a proper functioning of the banking sector and the transmission of monetary policy. Such policy interventions are intended to target temporary liquidity squeezes and market malfunctions, thereby absorbing systemic illiquidity risk (e.g., Rochet and Vives, 2004; Stein, 2012). However, the line between illiquidity and insolvency gets blurred during a systemic crisis, raising concerns that lender of last resort (LOLR) provision may be excessive (e.g., Calomiris et al., 2016; Drechsler et al., 2016). As banks access liquidity facilities by posting securities as collateral, LOLR may affect banks interlinkages through common collateral exposures. Understanding the pledging of securities by banks is particularly important as bank bonds are often used as a collateral in liquidity operations and, financial interlinkages among banks can exacerbate systemic risk (e.g., Acemoglu et al., 2015; Elliott et al., 2014; Freixas et al., 2000). Still, after more than a decade of experience with large scale liquidity operations, little is known about whether and how LOLR affects systemic risk.

In this paper, we show that LOLR policy affects bank interconnectedness and thereby systemic risk in the banking sector. Our analysis uses a novel micro-level dataset that links the securities pledged by banks to obtain LOLR funding with the haircuts applied by the LOLR and the private repo markets. This allows us to examine the haircut gap channel of the LOLR – i.e. the difference in valuation haircuts applied by the private market and the central bank for securities that can be pledged as collateral in repo operations.

We find that LOLR policy provides incentives for banks to increase their pledging of bonds associated with higher haircut gaps, especially those issued by other banks (more than sovereigns), and notably those issued by interconnected banks. This is consistent with theories of *interbank monitoring* (e.g., Rochet and Tirole, 1996) rather than *risk sharing* (e.g., Allen and Gale, 2000, 2007). This rise in interconnectedness is strong across similar banks, i.e. banks with correlated bond prices and domestic banks. Within domestic banks, high haircut gaps further increase the pledging of bonds issued by systemically important banks and the direct cross-pledging of bank bonds, consistent with theories of *bailout expectations* in the event of a systemic crisis (e.g., Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012). Furthermore, higher haircut gaps incentivize only banks (with LOLR access), and not other sectors (such as other intermediaries without LOLR access) to increase bank bond holdings. Finally, we document that LOLR policy stimulates the issuance of bank bonds associated with high haircut gaps. Our results uncover an important role for bank bonds as a source of collateral for other banks and show that LOLR policy increases bank interconnectedness, by encouraging the cross-holding of bank debt.

For identification, our analysis focuses on the provision of liquidity by the European Central Bank (ECB) in the period 2009–2015. The focus on the Eurozone offers an ideal setting to study the implications of LOLR policy for three reasons. First, it features a bank-dominated financial system which was adversely affected by both the Global Financial Crisis and the European Sovereign Debt Crisis. Second, the ECB played an active role in providing liquidity to banks in the form of repo against adequate eligible collateral. Total bank borrowing from the ECB, indeed, more than doubled during the Global Financial Crisis and reached unprecedented levels (a peak of EUR 1.2 trillion) at the height of the European Sovereign Debt Crisis. Third, it offers granular and comprehensive data which allow us to analyze the haircut gap channel of the LOLR.

We build a unique micro-level dataset that provides a detailed picture of the ECB and private repo markets. First, we observe banks' security pledging with the ECB in LOLR operations. The data covers individual security (ISIN) level information on bank- and government-issued securities pledged as collateral by all euro area banks to obtain LOLR funding. In addition to the amount of liquidity obtained by each individual bank at any given date, we observe rich information on the corresponding collateral pledged, including issuer, haircut, rating, residual maturity, price, security type, amount pledged and amount outstanding. Second, we match the confidential ECB data with private market haircuts provided by the two leading exchange and clearing houses in Europe: LCH Clearnet and EUREX. Our final dataset is at the ISIN-month-bank level over the period from January 2009 to March 2015.[1]

Our dataset allows us to assess the importance of the haircut gap at the most granular level. We construct a measure of security-level haircut gap (between the private market and ECB) at each point in time. A higher haircut gap means that the ECB applies a more favorable valuation of the asset as compared to the private repo market. Hence, this

[1] We end the sample in March 2015 to avoid overlapping with the start of the ECB quantitative easing policy which could potentially confound our findings.

higher gap increases the borrowing capacity of banks against the collateral pledged with the ECB. Not surprisingly, the highest haircut gaps are observed for bonds issued in periphery countries during the Sovereign Debt Crisis. We examine the effect of the haircut gaps on the pledging of securities to the LOLR. In our empirical strategy, we control for observables (e.g., security price and maturity) and unobservables (e.g., security, time, bank and rating group fixed effects). We first exploit the variation in the haircut gap in the full cross-section of securities and over the entire period. Second, for further identification we exploit specific ECB institutional rules that determine how the ECB haircuts depend on the ratings. Our main results are robust to alternative samples and identification settings.

We start our analysis by exploring the impact of the haircut gap on government- and bank-issued bonds pledged by banks to obtain LOLR funding. We show that banks increase the pledging of securities featuring higher haircut gaps. The effect is stronger for securities issued by other banks.[2] In terms of elasticities, a one standard deviation increase in the haircut gap (12 percentage points) is associated with a 1.9 percent increase in the pledging of bank-issued securities compared to the mean value at the bank level. The effect for sovereign bonds is instead around 1.2 percent.

We further show two novel stylized facts that help rationalize the importance of bank bonds highlighted by our results. First, bank bond holdings are concentrated within the banking sector while government debt is widely held across a range of sectors such as pension funds and insurance companies. This is consistent with banking being a particularly opaque industry (e.g., Morgan, 2002). Second, while sovereign debt constitutes an important source of pledged collateral, bank-issued securities represent the largest share of collateral type used in the ECB liquidity operations.

Next, we explore the variation in the haircut gap within the pledging of bank-issued bonds. Guided by the theoretical literature, we test whether LOLR is associated with higher pledging of bonds issued by similar banks, in line with theories of interbank monitoring (e.g., Rochet and Tirole, 1996), or bonds issued by less related banks to increase diversification via risk sharing (e.g., Allen and Gale, 2000, 2007). We find that stronger interconnectedness

[2] Our results are not driven by the pledging of own bonds or bonds issued within the same banking group which are excluded from the analysis.

arises across similar banks, consistent with the interbank monitoring theory. Higher haircut gaps increase bank linkages between issuing and pledging banks whose bond prices are ex-ante strongly correlated. They also incentivize the pledging of domestic bank bonds, which suggests segmented markets.[3] Results are especially strong for banks located in distressed (peripheral) countries, where haircut gaps are the most pronounced and risks in the banking sector are the highest. The effects of the haircut gap on the pledging of domestic bank bonds are around two times stronger than the average effect (3.5 percent increase compared to the mean value of pledged securities at the bank level).

Within domestic banks, we find that higher haircut gaps increase the pledging of securities issued by systemically important banks, consistent with theories of bailout expectations in the event of a systemic crisis (e.g., Farhi and Tirole, 2012). A one standard deviation increase in the haircut gap is associated with a 5.2 percent increase in the pledging of domestic bank bonds issued by systemically important banks compared to the mean value of pledged securities. In the baseline analysis, we measure banks' systemic importance with SRISK (Brownlees and Engle, 2017). Our results also hold for other measures of banks' systemic importance, such as size or leverage.

Moreover, we also find that a higher haircut gap is associated with an increase in the cross-pledging of bank bonds within domestic banks, consistent with the "too-many-to-fail" problem (e.g., Acharya and Yorulmazer, 2007). With cross-pledging, we refer to the situation in which bank A pledges more bank B bonds if in the previous period bank B pledged bonds issued by bank A. Following Elliott et al. (2014), our evidence is also consistent with integration motives (deeper relationships with each counterparty) as opposed to diversification motives (more counterparties). Further, the increase in the cross-holding concentration is also closely related to Goldstein et al. (2020) who show that homogeneity in bank' asset holdings amplifies the fragility of the financial sector. Our paper documents an additional layer of (direct) interconnectedness triggered by the cross-holding of bank bonds incentivized by LOLR haircut gap policy. Hence, we show that higher haircut gaps increase the direct linkages across banks.

[3] Our results suggest that there is some market segmentation, both across countries (domestic versus foreign) and across sectors (bank bonds are highly concentrated in the banking sector as compared to sovereign debt which is more widely held).

Next, we consider two identification strategies that rely on two specific institutional features of the ECB liquidity policy to further isolate the effect of haircut gaps on bank pledging. First, the ECB only applies two levels of haircuts across the rating scale: a lower haircut level for AAA to A- ratings and a higher one for BBB+ to BBB- ratings. Second, the ECB takes into account only the first best rating of the security when applying the haircut. As a result, the ECB increases the haircut only when all rating agencies downgrade the security to BBB+ or below.

In the first identification strategy, we exploit the nonlinearities (kinks/jumps) in the haircut gap with respect to the ratings. This identification relies on the fact that while the private market haircuts increase with every rating downgrade, the ECB haircuts are less sensitive to changes in ratings. Within a security class, the ECB haircut only jumps once. This jump occurs when the security risk is in the middle (at a downgrade from ratings A- to BBB+), while there is no change in ECB haircuts when the security risk is low (ratings between AAA and A-) or when the security risk is high (ratings between BBB+ and BBB-). This institutional feature allows us to empirically show that following a one rating downgrade, the pledging of bonds with the ECB increases by more at ratings that trigger a larger jump in the haircut gap.

The second identification strategy exploits the fact that the ECB considers only the best rating across four agencies (S&P, Moody's, Fitch and DBRS). As a result, a one notch downgrade at A- changes the ECB haircut valuation only if it affects the first best rating (binding downgrade). On the contrary, if at least one agency does not downgrade the security to BBB+ or below (non-binding downgrade), only the private market valuation haircut increases. While both non-binding and binding downgrades increase the perceived riskiness of the security, they have opposite effect on the haircut gap: non-binding downgrades increase the size of the haircut gap whereas binding downgrades decrease it. This setting allows us to test the hypothesis that non-binding downgrades provide greater incentives for banks to pledge more of the downgraded bonds with the ECB than binding downgrades. The analysis using the identification strategies confirm our results obtained from the full-sample.

We also provide an external validity of the effects of LOLR on systemic risk by exploiting the impact of the haircut gap on the holdings of bank securities across different sectors. We include both banking sector (that has access to the LOLR liquidity) and other placebo sectors (that do not have access to the LOLR) such as other financial intermediaries (e.g., mutual funds, pension funds and insurance companies) or non-financial sectors (firms, households and governments). We show that higher haircut gaps are associated with an increase in the holdings of bank-issued bonds only in the banking sector. On the contrary, the effect is negative for sectors that do not have access to LOLR.

Our main results are robust to a number of validation tests.[4] First, we show that our findings are not driven by banks' common exposure to sovereign risk. In particular, results remain strong even when controlling for issuer country-time fixed effects. Second, we introduce time-varying issuer or security fixed effects to address the potential concern that higher haircut gaps merely reflect higher security riskiness which would imply that our findings might be driven by security or issuer (bank) unobserved time-varying fundamentals. Relatedly, the results are robust to the introduction of bank-time fixed effects which capture all unobserved time-varying (pledging) bank fundamentals. To sum up, our results remain similar even after controlling for observable (e.g., maturity, rating group, price) and unobservable characteristics via issuer-, security-, country- and (pledging) bank-time fixed effects. Third, by excluding one country at a time we show that our results are not driven by any specific country. Fourth, within the second identification strategy based on the ECB rule of binding vs. non-binding downgrades, our results are robust to the use of rating data instead of haircut gaps. Fifth, our results are stronger after the introduction of the 3-year vLTRO policy which provided banks with even more favorable borrowing conditions from the LOLR, as it allowed banks to borrow at longer maturity. Sixth, we use the holdings of securities by banks across different countries and show that the effects of the haircut gap on bank holdings is consistent with that on pledging.[5]

[4] In the baseline, we use all securities pledged with the ECB (imputing the private market haircut for some securities via a machine learning algorithm). In the robustness, we analyze only the securities for which raw private market haircuts from clearing houses are available. The results are robust to these alternative samples.

[5] Using available matched security holding and pledging data, we show that on average banks pledge over 90% of the securities they hold. In addition, banks pledge over 75% of newly acquired securities within three months from the security issuance date. See Appendix Figure B1. This evidence suggests that banks do not merely start pledging previously held securities, but instead the increase in pledging reflects the increase in holding.

Finally, consistent with the main results, we show that banks whose debt is associated with higher ex-ante haircut gaps respond to an increased demand for their bonds by issuing more debt. This effect is particularly strong for banks in distressed (periphery) countries, where haircut gaps are substantially higher. Importantly, banks do not merely use the market timing to replace their maturing debt but instead increase their overall dependence on bond market financing.

Contribution to the literature. Our work contributes to several strands of the literature. A large body of LOLR literature has provided theoretical arguments regarding the beneficial effects of LOLR policy arising from the provision of liquidity to temporarily illiquid but otherwise solvent institutions (e.g., Bagehot, 1873; Diamond and Dybvig, 1983; Freixas et al., 2010; Rochet and Vives, 2004; Stein, 2012), with more recent empirical evidence showing the positive effects on lending (e.g., Jasova et al., 2021; van Bekkum et al., 2018) and financial markets (e.g., Pelizzon et al., 2020). Our paper most closely relates to Drechsler et al. (2016) who show that ECB liquidity operations are accessed more by ex-ante weakly capitalized banks who use the central bank funding to purchase more risky distressed sovereign bonds in the aftermath of the first Greek bailout (June 2010 to December 2011). While Drechsler et al. (2016) focus on government debt, our focus is on the pledging of bank bonds. We complement previous findings by showing that bank bonds are also an important source of collateral and exhibit higher sensitivity to LOLR policy with implications for bank interconnectedness and consequently the buildup of systemic risk.[6]

Our paper also relates to the literature on systemic risk. While most of the literature analyzes systemic risk emerging from linkages via the interbank market (e.g., Abbassi et al., 2021; Acemoglu et al., 2015; Allen and Gale, 2000; Cabrales et al., 2017; Iyer and Peydro, 2011), we explore systemic risk that arises from the cross-holding of bank-issued securities.[7] Such cross-holdings of bank bonds are large and dominate the securities pledged as a collat-

[6]While the implications of LOLR policy for the sovereign-bank nexus are well understood (e.g., Acharya and Steffen, 2015; Altavilla et al., 2017; Battistini et al., 2014; Drechsler et al., 2016), the impact of LOLR on the interconnectedness and concentration of bank risks has so far been unexplored.

[7]We provide evidence on the effects of LOLR policy on interconnectedness and the buildup of systemic risk in the banking sector. Importantly however, our results do not imply that LOLR increases overall systemic risk but that it increases systemic risk at the margin by encouraging the cross-holding of bank bonds.

eral with the central bank.[8] We show that through higher haircut gaps, the LOLR stimulates the buildup of systemic risk via banks' pledging of bonds issued by other similar (more correlated or domestic) banks. These results cannot be explained by risk sharing motives as in Allen and Gale (2000, 2007) or by a broad reach for yield (see e.g., Adrian and Shin, 2010; Becker and Ivashina, 2015; Martinez-Miera and Repullo, 2017; Rajan, 2006). Instead they are more consistent with the literature on peer monitoring across similar banks (see e.g., Elliott et al., 2014; Freixas et al., 2000; Rochet and Tirole, 1996). Moreover, our results show that banks pledge more bonds issued by domestic systemically important banks, as well as, cross-pledging of bank bonds. Both results are consistent with systemic bailout theories (see e.g., Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012). Our findings are also closely related to Goldstein et al. (2020) who show that homogeneity in banks' asset holdings amplifies the fragility of the financial sector.

Finally, this paper also links to the literature on monetary policy and risk taking (e.g., Adrian and Shin, 2010; Allen et al., 2011; Dell'Ariccia et al., 2017; Di Maggio and Kacperczyk, 2017; Diamond and Rajan, 2011; Jimenez et al., 2014; Maddaloni and Peydró, 2011; Rajan, 2006). Our paper provides evidence on systemic as opposed to individual (bank) risk taking. In addition, by exploring the systemic risk implications of central bank liquidity policy in crisis times, we complement the growing number of studies that assess the implications of unconventional policies for financial markets (e.g., Chodorow-Reich, 2014; Koijen et al., 2021; Krishnamurthy et al., 2017; Krishnamurthy and Vissing-Jorgensen, 2011) and bank lending (e.g., Chakraborty et al., 2018; Di Maggio et al., 2020; Rodnyansky and Darmouni, 2017; Peydro et al., 2021).

The remainder of the paper is organized as follows. Section 1 introduces the institutional background. Section 2 presents the data and Section 3 the empirical strategy. Section 4 analyses the pledging of bank- and government-issued securities. Section 5 presents the results on systemic risk while Section 6 exploits ECB haircuts rules. Section 7 provides additional results and robustness to the systemic risk results. Section 8 draws implications for the issuance of bank debt. Finally, Section 9 concludes.

[8] In the euro area, the cross-holding of bank-issued securities has become more relevant than interbank deposits in recent times (e.g. ECB, 2015). See also Bekaert and Breckenfelder (2019) for the evolution of the cross-holding of bank bonds over more recent years.

1 Institutional Background

This section presents stylized facts regarding the key holders of bank and government bonds in the euro area. In addition, it provides relevant information on the ECB liquidity framework and the pledging behavior by banks.

1.1 Bank Bond Holdings

Figure 1 compares the holdings of bank and government securities in the euro area, which are at the core of our analysis. European banks hold a remarkably large share of bonds issued by (other) banks. Further, while banks are the largest holders of bank-issued bonds in the economy, the holding of government bonds is more equally spread across different institutional sectors. In addition, banks generally hold largest shares of domestically issued securities, including bank bonds. Hence, bank risk is heavily concentrated in the domestic banking sector. This is consistent with banking being a particularly opaque industry (e.g., Morgan, 2002). While the existing literature has shown important results on the holding of distressed-sovereign debt by banks (e.g., Acharya et al., 2014; Acharya and Steffen, 2015; Altavilla et al., 2017; Battistini et al., 2014; Drechsler et al., 2016), we complement previous findings by documenting that euro area banks are also greatly exposed to bank risk, at least as much as to sovereign risk.

1.2 Central Bank Liquidity Operations

The ECB provides liquidity in the form of repurchase agreements (repo) to banks operating in the euro area.[9] In the aftermath of the Global Financial Crisis, the ECB strengthened the LOLR function embedded in the regular monetary policy operations and "*adopted a genuinely classical approach to [...] LOLR responsibilities*" (Praet, 2016).[10]

[9] This paper focuses on the LOLR funding built into the monetary policy operational framework, which provides the bulk of liquidity to the banking system. The ECB features a number of counterparties that is remarkably higher than other major central banks. We abstract from the lending under the Emergency Liquidity Assistance program that is administered by national central banks and which falls outside the Eurosystem monetary policy operations. For details on the Eurosystem collateral framework, see Bindseil et al. (2017).

[10] Until 2008, the provision of liquidity in the main refinancing operations (MRO) was implemented through auctions at variable rate. Cassola et al. (2013) provide details on the primary auctions of liquidity and an

Figure 2 summarizes the development of ECB liquidity received by all banks in the euro area. Total bank borrowing from the ECB increased remarkably following the Lehman Brothers collapse and reached a peak of EUR 1.2 trillion in the middle of the European Sovereign Debt Crises. The Eurozone, hence, represents an ideal laboratory to study LOLR policy of unprecedented magnitude.

Eligible collateral. To ensure the availability of sufficient collateral across a large number of banks and countries, the ECB provides liquidity against a wide range of eligible assets. Securities eligible as a collateral for LOLR operations need to meet the minimum requirement of a first best credit assessment of at least credit quality step 3 (rating of BBB- or equivalent) obtained from external credit assessment institutions (S&P, Moody's, Fitch and DBRS).[11]

Pledged collateral. What do banks pledge with the LOLR as a collateral? Figure 3 Panel (a) shows that while sovereign debt (in blue) undoubtedly constitutes an important source of pledged collateral, bank-issued bonds (in red) represent the largest share of collateral asset type pledged with the ECB. Figure 3 Panel (b) zooms on the pledging of bank-issued securities and compares the pledging of domestic and foreign bank-issued securities by geographical location of the pledging bank (core vs. periphery).[12] Domestic bank-issued bonds were disproportionately more used as a collateral by banks located in core countries in the aftermath of the Global Financial Crisis. However, since the start of the European Sovereign Debt Crisis, banks located in distressed periphery countries remarkably increased their pledging of bonds issued by other domestic banks. The evolution of the pledging of bank-issued bonds displayed in Figure 3 Panel (b) is consistent with the evolution of bank bond holdings reported in Figure 5.

In our analysis, we focus on the security pledging by banks. It is however worth noticing that changes in the pledging behavior reflect the actual changes in the holdings of securities (as opposed to the delayed pledging of previously held collateral). We compare banks'

analysis of euro area banks' bidding behavior under the multiple rate auction during the 2007 sub-prime market crisis. Afterwards, the ECB started to provide unlimited allotment, hence, fully satisfying all bank bids associated with the pledging of sufficient eligible collateral.

[11]To make the credit ratings comparable across systems and sources, the grades are mapped to a harmonized rating scale. For detailed information on the Eurosystem's harmonized rating scale see https://www.ecb.europa.eu/paym/coll/risk/ecaf/html/index.en.html.

[12]Periphery countries denote Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands.

pledging vs. holding behavior and show that on average banks pledge over 90% of securities held.[13] In addition, the timing of the pledging of newly issued securities suggests that banks pledge over 75% of newly acquired securities within three months from the security issuance date. This is also consistent with the previous micro-data evidence that documents that security holding and pledging of banks are strongly correlated (see Jasova et al., 2021).

Haircuts. The amount of liquidity a bank can obtain from the ECB against the collateral pledged crucially depends on the applied haircut. The ECB haircut valuation is primarily determined by a combination of issuer group (government, bank, etc.), asset type (covered bonds, uncovered bonds, etc.), coupon type (floating and fixed), rating and residual maturity. The basic valuation matrix as well as any temporary or permanent changes to this valuation framework are publicly communicated and made available by the ECB.[14] Additionally, the ECB publishes daily the list of eligible securities (at the ISIN-level) that allows to precisely observe the haircut applied to each security submitted as a collateral in LOLR operations.[15]

Prior to the Global Financial Crisis, the haircuts applied by the ECB were similar to the private market haircuts on repo loans. However, afterwards, the ECB started offering haircuts significantly below that of the private repo markets. Specifically, over the 2009–2015 period, the ECB applied average haircuts of 5.9% while private market average haircuts were close to 12% (see Table 1 (top panel)).

Interest Rates. While the central bank offers below-market haircuts, it charges an interest rate above the private repo rates (Drechsler et al., 2016). In line with the Bagehot principle, the ECB provides unlimited allotment of funds to European banks against adequate collateral at a "penalty" rate. Online Appendix Figure B2 compares the evolution of the borrowing rates from the ECB and from the private repo market against the General Collateral and documents that higher rates are charged by the LOLR compared to the private markets.

[13]Data on individual banks' security holdings are only available for a subset of banks used in our analysis on the quarterly frequency for the 2014–2018 period. For details, see Online Appendix Figure B1.

[14]See https://www.ecb.europa.eu/paym/coll/risk/liquidity/html/index.en.html for ECB haircut valuation details. In addition to marketable securities, banks occasionally pledge non-marketable assets, namely additional credit claims. The eligibility of these assets is determined by the national central banks and they follow internal valuations set by the ECB. Nevertheless, the share of the non-marketable securities is not sizable (less than 5% of all pledged assets). This paper focuses on marketable securities widely accepted also by the private repo market.

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

Hence, for the collateral associated with very low haircut gaps, banks have a higher incentive to borrow in private markets.

2 Data

We construct a unique micro-level dataset that matches ECB data on liquidity and collateral with private repo market haircuts, and bank balance sheet data. The richness and granularity of our dataset allows us to exploit the impact of LOLR policy via the haircut gap channel across a large number of securities, banks and countries. The dataset covers the January 2009 – March 2015 period, hence, capturing the European Sovereign Debt Crisis.[16] To the best of our knowledge, our paper is the first to provide a systematic and comprehensive assessment of the haircut gap channel of LOLR policy.

Central bank liquidity and collateral data. The Market Operations Database (MOPDB) is an ECB internal source that contains granular data on all liquidity operations and collateral pledged by European banks to obtain liquidity from the ECB. This is the largest cross-country liquidity and collateral dataset covering the monetary policy operations of the euro area. In addition to the amount of liquidity obtained by each individual bank at any given date, MOPDB provides detailed information for more than 20,000 unique bank- and government-issued securities pledged as collateral by banks. The main variables used in the analysis are International Security Identification Number (ISIN), issuer group (bank, government,etc.), security type (bond, note, covered bond, ABS, etc.), issuance and maturity date. MOPDB also reports the amount pledged by each individual entity and the total amount outstanding. In addition, it reports information on valuation (market value, ECB haircut and haircut-adjusted value). All information is available at the level of each ISIN-bank-time. This is crucial for our analysis, as it allows to assess the importance of LOLR policy at the most granular level and with extraordinary breadth and coverage.

Private haircuts. Next, we create a novel dataset that provides a detailed picture of the ECB and private repo markets in Europe. To this end, we collect private repo market data

[16]We end our sample in March 2015 to avoid any overlap with the Asset Purchase Program of the ECB. On March 9, 2015 the Eurosystem started to conduct purchases of public sector securities.

from the two leading exchange and clearing houses in Europe: LCH Clearnet and EUREX. Our analysis uses the market haircuts of securities posted in the private markets in two ways. We either analyze all possible securities (imputing the private haircut for some securities via a random forest machine learning prediction algorithm) or only analyze the securities with raw information from the clearing houses. Our results are robust to both samples.[17]

Securities and issuer ratings. The Centralized Securities Database (CSDB) consolidates security-by-security data (instruments, issuers and prices) from both ECB internal and commercial sources. It provides ratings on the credit quality of marketable securities according to the external credit assessment institutions: S&P, Moody's, Fitch and DBRS. The information is reported at the ISIN-time and issuer-time level for all securities issued by EU residents or denominated in euro.

Bank-level data. We link the collateral and liquidity data to bank-level data. The proprietary Individual Balance Sheet Items (IBSI) database, maintained by the ECB, contains monthly-level information on the granular asset and liability categories for about 340 most important banks operating in the euro area. We construct time-varying bank level controls such as size, ratio of security holdings to total assets, equity ratios. Furthermore, we collect data on bank ownership structure from Bankscope and the Register of Institutions and Affiliates Database (RIAD) to create the group structure of banks. Using this information, we can exclude the pledging of bank bonds issued by the same bank or by the same bank holding group. As a result, in the analysis we only examine the pledging of bank bonds that were issued by *other* banks. Finally, we use information on banks' bond and equity prices, and leverage from Datastream to construct the SRISK measure (see Brownlees and Engle, 2017).[18]

Security holdings data. We use Securities Holdings Statistics (SHS) data that provide information on security-by-security holdings of debt securities by institutional sectors in the euro area on a quarterly basis.[19] The high granularity of the data (ISIN-level) allows us to

[17]For details about the random forest, see Online Appendix A. Alternatively, we also repeat the prediction exercise using a Bayesian Model Averaging (BMA) approach and simple linear regressions. The results of all prediction techniques as well as the raw sample are reported in the Online Appendix Table A1.

[18]We are grateful to Christian Brownlees for sharing the programming code to compute SRISK using Matlab.

[19]We group the sectors into banks, other financial institutions (OFIs) insurance companies and pension

document the main holders of bank and government bonds. In addition, we also use the SHS data to compare the evolution of the holdings of bank bonds by banks and other sectors in the external validity exercise.

3 Empirical Strategy

3.1 Haircut Gap

We use the haircut gap as a measure of the LOLR policy. The haircut gap is the difference between the private market and ECB valuation of a pledged security s at time t:

$$\text{HaircutGap}_{s,t} = \text{private market haircut}_{s,t} - \text{ECB haircut}_{s,t} \tag{1}$$

In the baseline specification, the private market haircut for security s in month t is imputed with a machine learning random forest technique that uses security's observable characteristics (issuer group, issuer rating, coupon type and residual maturity basket).[20] In the robustness, we show that our findings hold also when using only the raw (unimputed) data. The ECB haircuts are directly observed in the ECB's Market Operation Database at the ISIN-month level.[21]

Table 1 (top panel) provides the summary statistics. The average haircut gap for securities in our sample is 6.1 percentage points with a standard deviation of 12 percentage points. In detail, ECB applied average haircut of 5.9% while private market haircuts average to 12%. Figure 4 illustrates the diverging trajectory of the haircut gap by securities issued in core and periphery countries. Since the downgrade of Greece in April 2010, the Eurozone experienced a wave of rating downgrades of securities in periphery countries. These rating

funds (ICPFs), Households (HH), central government (Gov), non-financial corporations (NFCs) and others.

[20] This approach allows us to avoid the potential selection bias related to the fact that reported private market haircuts are available only for the subset of securities. In particular, high haircut gap securities may be underrepresented in the private market haircut data because banks with access to the LOLR facilities can obtain larger liquidity against them from the central bank. These securities still appear in our dataset because they are used in the private market repo transactions by other financial institutions without access to the LOLR. For details about the machine learning algorithm, see Online Appendix A.

[21] Both the ECB and the private market haircuts for repo transactions cleared by the central counterparty (i.e., EUREX or LCH Clearnet) do not depend on the identity of the borrowing bank.

downgrades substantially increased private market haircuts and thus limited the borrowing capacity of banks from private repo market against this risky collateral. In contrast, the ECB did not increase the haircuts on risky securities to the extent observed in the private market.

The deepening of the European Sovereign Debt crisis therefore exacerbated the gap between the private and ECB haircuts on the securities issued in periphery countries. In Figure 4, we illustrate a significant increase in the haircut gap for securities issued in periphery countries. We also document that this overall divergence holds for periphery countries at large even if we exclude the unique case of Greek bonds.[22]

3.2 Full Sample Analysis

In the first part of the analysis, we exploit the variation in the haircut gap at the cross-section of securities (ISIN-level) and over time. We examine the effects of changes in the haircut gap on the pledging behavior of banks in the euro area using the full sample of securities. We test the hypothesis that banks increase pledging of securities characterized by higher haircut gaps. We also investigate the heterogeneous effects across different securities and banks. The baseline empirical specification estimates how changes in the haircut gap impact the security pledging of banks with the LOLR. Equation (2) summarizes the setup:

$$\begin{aligned}\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} &= \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1 \text{HaircutGap}_{s,t-1} + \beta_2 (\text{HaircutGap}_{s,t-1} \times \text{H}_{s,b}) + \\ &+ \gamma \text{H}_{s,b} + \delta X_{s,t-1} + \epsilon_{s,b,t}\end{aligned} \tag{2}$$

The main outcome variable is the pledged value of security s by bank b in month t, expressed as a share of the total value outstanding of this security. This allows us to examine the importance of the pledging with LOLR over time re-scaled by the total amount available.[23] In Section 4, we consider marketable securities which are issued by both the central governments and banks in euro area countries. In the main part of the paper, which exam-

[22]Over our sample period, Greek assets were not always eligible. In particular, in February 2012, in the second half of 2012 and since early 2015 marketable debt instruments issued or fully guaranteed by the Greek government become ineligible for use as collateral in Eurosystem monetary policy operations.

[23]As our outcome variable is re-scaled by the value outstanding of security s, the results are not mechanically driven by the size of the issuing bank or amount issued. Moreover, the introduction of security fixed effects allows us to further control for time-invariant security (issuer) characteristics, such as issuer size.

ines the systemic risk arising from bank interconnectedness, we only focus on bank-issued securities.

HaircutGap$_{s,t-1}$ refers to the difference in the haircut valuation of security s by private repo markets and the central bank (see Equation (1)). In addition to the average effect of the haircut gap on the banks' pledging behavior, we also focus on the heterogeneous effects. In Equation (2), we refer to the heterogeneity in a general way as $H_{s,b}$. In the following sections, we provide detailed explanation of these heterogeneities as we address different effects of the LOLR policy.

Importantly, we saturate the specification with observable controls and fixed effects. We control for time fixed effects (α_t) that capture developments in macro, financial and monetary conditions, and pledging bank fixed effects (α_b) to control for bank-specific time-invariant characteristics. Further, we saturate the specification also with security (ISIN) fixed effects (α_s). This allows us to control for permanent security-level characteristics (such as issuer, coupon payments or existence of guarantees). In addition, we progressively introduce time-varying controls (security price and residual maturity) denoted by $X_{s,t-1}$. Finally, we introduce rating group fixed effects (α_r) to control for time-varying security riskiness.[24] In Section 7, we corroborate the key findings by saturating the specification with high-order fixed effects. We add country-time and issuer-time fixed effects to control for sovereign and issuer risk. We also introduce ISIN-time fixed effects to subsume security controls, and bank-time fixed effects to control for time-varying variation of the pledging bank. Our standard errors are two-way clustered at the security and time level.

3.3 Empirical Strategies: ECB Institutional Rules

In the second part of the analysis, we restrict the sample to exploit two specific institutional features of the ECB haircut policy: (i) the two-step haircut profile and (ii) the first best rating rule.

Kinks and jumps in haircut gaps. In this first identification strategy, we exploit the nonlinearities in the haircut gap sensitivity with respect to the rating. For each type of

[24] We group ratings following the three rating steps system used by the ECB: AAA to AA- (Step 1), A+ to A- (step 2) and BBB+ to BBB- (Step 3).

security the ECB applies only two discrete levels of haircuts: a lower haircut value if the rating is equal or better than A-, and a higher haircut if the rating ranges between BBB+ and BBB- notch.[25] Hence, while private markets adjust their haircut valuation at every notch downgrade, the ECB haircuts only react to rating changes between A- and BBB+. As a result, a (one notch) change in ratings affects the haircut gap differently depending on the ex-ante rating level.

Figure 6 illustrates the intuition behind this identification strategy. The figure shows the relationship between the rating and the haircut levels for a representative class of pledged assets (i.e. unsecured bond issued by credit institution with 1-3 years residual maturity and fixed coupon payments). Panel (a) depicts the haircuts (in percent) set by the ECB and the average haircuts applied by the private market. As mentioned, the ECB haircut profile (in red) is markedly flat with only one jump from A- to BBB+. That is, within a security class, the ECB haircut only jumps once (from A- to BBB+), and there are no other jumps between AAA and A- (low risk) or between BBB+ and BBB- (high risk). The private market haircut profile is instead upward sloping with substantial non-linearities. Most notably, the private market on average applies large increments in haircuts at the bottom tier of the investment grade rating.

Figure 6 Panel (b) shows the average haircut gap at each best rating notch. The differences in sensitivity to rating of haircuts applied by the ECB and the private market create a non-linearity in the haircut gap profile with kink and jumps. For example, a one notch downgrade from A+ to A yields on average an increase in haircut gap by 1 percentage point while a downgrade from A to A- delivers a haircut gap hike of 6 percentage points.

To implement this strategy, we restrict the sample to the period of +/- 2 months around the event of a one-notch rating change and exploit the effect of the kinks and jumps in the non-linear haircut gap profile on the banks' pledging behavior described by Equation (2). We empirically test the hypothesis that following a one notch downgrade, the security pledging with the ECB increases by more at rating notches which trigger a larger jump in the haircut gap.

[25] By type, we refer to a security of the same asset class, institutional type of issuer, residual maturity and structure of coupon payments. For details, see: https://www.ecb.europa.eu/press/pr/date/2010/html/sp090728˙1annex.en.pdf.

Binding and non-binding downgrades. The second identification strategy exploits another key institutional feature of the ECB haircut policy: *the first best rating rule*. While private markets generally react to the downgrade of any rating agency, the ECB considers only the best rating among the four rating agencies (S&P, Moody's, Fitch and DBRS).

We restrict the sample of securities with the best rating at the A- cliff and we exploit the variation in the haircut gap following a one notch downgrade. We get the identification from distinguishing two types of downgrades from the perspective of the ECB: *binding*, i.e. the best rating of the four agencies moves to BBB+; or *non-binding*, i.e. at least one rating agency continues to rate the debt at A- (i.e., some but not all rating agencies have downgraded the security). In case of a binding downgrade, both ECB and private markets increase haircut levels. If the downgrade is non-binding, ECB continues to apply the lower haircuts (associated with A-) and only private markets increase the haircuts. As a result, non-binding downgrades increase the size of the haircut gap while binding downgrades decrease it.

This strategy in the restricted sample further allows us to address the correlation between security risk and haircut gaps. As any downgrade, a binding downgrade from A- to BBB+ undoubtedly reflects a deterioration in risk quality. However, in contrast to the non-binding downgrade, the haircut gap is reduced in the case of a binding downgrade, as on average the ECB haircut increases by more than the private market one. Note that the market haircut reacts to all rating downgrades, while the ECB only reacts to the final (first best) one. As a consequence, this strategy allows us to test whether it is an increase in the haircut gap or an increase in bond riskiness that incentivizes banks to increase their pledging with the LOLR. An alternative approach to tackle this issue is to directly control for the issuer risk with issuer-time or security-time fixed effects. We present the results of this analysis using the full sample in Section 7.3.

4 LOLR and Banks' Pledging Behavior

We start our analysis by examining the impact of the haircut gap on the security pledging behavior of banks to obtain LOLR funding. Motivated by the evidence in Section 1, we investigate the similarities and differences related to the use of bank- and government-issued bonds as a collateral in LOLR liquidity-providing repo operations.

The existing literature has largely focused on examining the role of government bonds (e.g., Acharya and Steffen, 2015; Drechsler et al., 2016). However, as shown in Figure 1, banks' exposure to risk within the banking sector is at least as important as the exposure to sovereign risk. In addition, bank-issued debt is disproportionately more used as collateral with the ECB compared to government-issued debt and the importance of bank bonds pledged by banks located in periphery countries increased substantially during the Sovereign Debt Crisis. Hence, exploring the impact of LOLR on the pledging of bank-issued securities is crucial to understand its effect on bank interconnected and systemic risk.

Specifically, we first test the hypothesis that banks increase the pledging of securities featuring higher haircut gaps. Second, we explore the heterogeneous impact of the haircut gap on security pledging and examine the differential effects for bank bonds. Equation (3) summarizes the set-up:

$$\begin{aligned}\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = {} & \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1 \text{HaircutGap}_{s,t-1} + \\ & + \beta_2(\text{HaircutGap}_{s,t-1} \times \text{Bank Bond}_s) + \delta X_{s,t-1} + \epsilon_{s,b,t}\end{aligned} \tag{3}$$

Table 2 summarizes the results. Column (1) shows that banks increase their pledging of securities featuring higher haircut gaps. The table reports positive and statistically significant estimates of similar magnitudes even after including the security-level controls (Column (2)) and the rating group fixed effects (Column (3)).

Table 2 further highlights that the impact of higher haircut gaps on banks' pledging with the LOLR is stronger for bank bonds than for sovereign debt. In terms of elasticities, a one standard deviation increase in the haircut gap is associated with a 0.08 (0.05) percentage point increase in the pledging of bank (government) bonds as a share of bonds outstanding at the individual bank level. This effect is economically significant and corresponds to a 1.9 percent (1.2 percent) increase compared to the mean value of pledged bonds as a share of the value outstanding at the individual bank level.[26] As shown in Figure 1, the holdings of bank bonds are heavily concentrated in the balance sheet of banking institutions who have

[26] Formally, we compute an effect of a one standard deviation increase in haircut gaps on pledging of bank

access to the LOLR facilities. These are, therefore, the type of securities more sensitive to changes in the haircut gap. Government bonds are instead more widely held by other financial institutions, such as pension funds or mutual funds. Consistently, these assets are less sensitive to changes in the valuation of the LOLR for the provision of liquidity, as the latter can be only exploited by banks.

To summarize, our results highlight that through favorable haircut gaps, the LOLR benefited more the pledging of bank-issued securities, as compared to government bonds. In Section 5, we explore how LOLR affects the pledging of different types of bank-issued bonds and their implications for the buildup of systemic risk in the banking sector.

5 Systemic Risk: Full Sample

In this section and throughout the rest of the paper, we concentrate the analysis on bank bonds. We focus on what type of bank-issued securities benefited the most from a favorable haircut gap. This examination allows us to further test whether higher haircut gaps increase systemic risk. We explore whether the haircut gap provides incentives for banks to pledge bonds issued by (other) banks which are similar to them, or by systemically important banks. Further, we also explore if it increases bank bond cross-pledging. Importantly, we exclude the pledging of own issued and retained bonds, as well as, bonds issued by other banks in the same banking group.

5.1 Similarity Across Banks

We start by exploring variation within bank bonds to assess whether the haircut gap provides incentives to banks to increase their pledging of bonds issued by banks similar to them. We measure bank similarity in two ways. First, we use the correlation between bond prices of

---

bonds as follows:

$$100 \times \frac{(\beta_1 + \beta_2) \times \textit{std. of haircut gap}}{\textit{mean value of pledged bonds}} = 100 \times \frac{(0.00307 + 0.00522) \times 0.1197}{0.0516} = 1.9\%$$

where β_1 and β_2 are estimates from Table 2 (see Equation (3)) while standard deviation of haircut gap and the mean value of pledged bonds as a share of the value outstanding at the individual bank level are taken from Table 1.

the pledging and the issuing bank. Second, we consider the geographic location of the issuing bank and examine differences in pledging of domestic and foreign bonds.

Correlation of bond prices. We use banks' bond prices to measure similarity across banks. Specifically, we compute the ex-ante correlation of bond prices of the pledging and the issuing bank using the bond price data over the previous three years. We examine the effect of bond price correlation on systemic risk according to the following specification:

$$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1 \text{HaircutGap}_{s,t-1} + \\ + \beta_2(\text{HaircutGap}_{s,t-1} \times \text{Correlation}_{s,b,t-1}) + \gamma \text{Correlation}_{s,b,t-1} + \delta X_{s,t-1} + \epsilon_{s,b,t} \quad (4)$$

The results in Table 3 show that the estimate of the interaction coefficient of the haircut gap with the correlation measure is positive and statistically significant across all specifications and it does not attenuate even after controlling for the security rating group. This suggests that the haircut gap increases bank linkages between issuing and pledging banks whose bonds are ex-ante strongly correlated (thereby proxying for higher bank interconnectedness).

Domestic vs. foreign bank bonds. Next, we split the securities issued by banks in two categories: domestic and foreign. A security is denoted as domestic if the pledging and issuing banks have the same country of location, and as foreign otherwise. Equation (5) summarizes the set-up:

$$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1(\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}) + \\ + \beta_2(\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,b}) + \gamma \text{Domestic}_{s,b} + \delta X_{s,t-1} + \epsilon_{s,b,t} \quad (5)$$

Table 4 presents the results. All specifications highlight that the increased pledging of bank-issued bonds associated with higher haircuts is attributable to the pledging of bonds issued by domestic banks. Foreign bank bonds instead deliver non-significant estimates. Our findings suggest that the LOLR contributes to an increase in the concentration of bank risk within the domestic banking sector. The effects of the haircut gap on the pledging of domestic bank bonds are around two times stronger than the average effect, i.e. 3.5 percent increase compared to the mean value of pledged securities at the individual bank level.[27]

Domestic bank bonds in core vs. periphery. In light of these findings, we examine the following questions: do we observe an increase in the allocation of risk within the banking sector across the Eurozone as a whole? Or, is there a disproportionately higher buildup of systemic risk in periphery countries where security haircut gaps are the most sizable?

To address these questions, we complement the previous analysis with an additional source of regional heterogeneity. Motivated by the heterogeneous evolution of haircut gaps in core vs. periphery (Figure 4), we split the pledging banks into two categories: $Periphery_b$ and $Core_b$. We combine these two margins to create four distinctive categories. Equation (6) summarizes the set-up:

$$\begin{aligned} \frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = {} & \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1(\text{Periphery}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ & + \beta_2(\text{Periphery}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ & + \beta_3(\text{Core}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ & + \beta_4(\text{Core}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ & + \gamma_1(\text{Periphery}_b \times \text{Domestic}_{s,b}) + \gamma_2(\text{Periphery}_b \times \text{Foreign}_{s,b}) + \\ & + \gamma_3(\text{Core}_b \times \text{Domestic}_{s,b}) + \delta X_{s,t-1} + \epsilon_{s,b,t} \end{aligned} \tag{6}$$

The results in Table 5 show that the effects are driven by domestic banks located in periphery countries, where the haircut gap is the most pronounced and the risks in the banking sector are the highest. By providing a favorable haircut gap, the LOLR incentivizes the concentration of bank risk within the domestic banking sector, especially in periphery countries. Our findings provide new insights to explain the disproportional holdings of bank risk by other banks in the Eurozone, with especially high domestic concentration in periphery

[27] Formally, we compute an effect of a one standard deviation increase in haircut gaps on pledging of domestic bank bonds as follows:

$$100 \times \frac{\beta_1 \times \textit{std. of haircut gap}}{\textit{mean value of pledged bonds}} = 100 \times \frac{0.0151 \times 0.1197}{0.0516} = 3.5\%$$

where β_1 is an estimate from Table 4 (see Equation (5)) while standard deviation of haircut gap and the mean value of pledged bonds as a share of the value outstanding at the individual bank level are taken from Table 1.

countries. This result is also consistent with the overall evolution of bank bond holdings by other banks presented in Figure 5. Consistent with the regression results, Figure 5 shows a distinct increase in the holdings of domestic bank bonds by other banks in periphery countries in periods of high haircut gaps.

To summarize, by showing that banks increase by more the use of collateral issued by other similar banks, our results support the idea that the decision of banks to purchase securities issued by their peers is reinforced by their monitoring abilities (see e.g., Rochet and Tirole, 1996; Freixas et al., 2000). This is also consistent with the banking industry being very opaque (Morgan, 2002) and hence with more substantial monitoring needs. In addition, our evidence on the rise in interconnectedness among domestic banks is consistent with segmented markets. Furthermore, we do not find evidence that banks located in periphery countries increase their pledging of bonds issued by banks located in foreign countries. This suggests that our findings cannot be explained by the diversification or insurance motive as in Allen and Gale (2000, 2007) or by the broad reach for yield rational (see e.g., Adrian and Shin, 2010; Becker and Ivashina, 2015). According to the latter, we should expect a higher loading on risky, high-haircut-gap securities across the entire set of high yield assets regardless of the country of issuance (i.e. domestic or foreign bonds). In contrast, we find evidence of increased pledging only of domestic securities issued by banks in periphery countries.

5.2 Systemically Important Banks

So far, we have established that the haircut gap contributes to the higher interconnectedness within the national banking sector especially in periphery countries. In this section, we further explore the implications of the haircut gap for systemic risk through the role of systemically important banks.

To this end, we use SRISK as a measure of the systemic risk contribution of banks. In line in Brownlees and Engle (2017), we compute SRISK as a function of bank's size, leverage and long run marginal expected shortfall for all available euro area banks.[28] Finally, we

[28] In the estimation procedure, we use an extended data period from 2000 to 2015. The baseline result

construct a binary indicator that denotes banks as systemically important if their SRISK ratio is in the top 10% of SRISK of all banks in the respective country, and as 0 otherwise.[29]

Given the results presented in previous section, we investigate the effects on systemically important banks also in interaction with the Domestic categorical variable. Equation (7) summarizes the triple interaction set-up:

$$
\begin{aligned}
\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = {} & \alpha_s + \alpha_b + \alpha_t + \alpha_r + \beta_1(\text{SRISK}_{s,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\
& + \beta_2(\text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}) + \beta_3(\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\
& + \beta_4\text{HaircutGap}_{s,t-1} + \gamma_1(\text{Domestic}_{s,b} \times \text{SRISK}_{s,t-1}) + \gamma_2\text{Domestic}_{s,b} + \\
& + \gamma_3\text{SRISK}_{s,t-1} + \delta X_{s,t-1} + \epsilon_{s,b,t}
\end{aligned}
\tag{7}
$$

The results, reported in Table 6, show that in response to higher haircut gaps banks pledge more securities issued by other domestic banks (β_3). Importantly, we find a stronger response for securities issued by more systemically important domestic banks (β_1). Interestingly, the increase in the pledging of bonds issued by banks with higher SRISK is not a generalized phenomenon, i.e. the estimate of β_2 is negative, indicating that the stronger effect for systemically important banks is observed only within the domestic banking sector.[30] In terms of elasticity, a one standard deviation increase in the haircut gap is associated with a 5.2 percent increase in the pledging of domestic bank bonds issued by systemically important banks compared to the mean value of pledged securities. In addition to the complex measure of SRISK, we also repeat the analysis by using the bank size (total assets) and equity ratio as simple proxies for the banks' systemic importance. We discuss these results in the robustness part of the paper in Section 7.

Our findings are consistent with the systemic bailout theory proposed by Acharya and

uses 22 horizons, systemic event threshold of -10% and the STOXX Europe 600 Banks as market index. For robustness, we also reconstruct the index using different horizon, systemic event thresholds as well as STOXX Europe 600 as an alternative market index. Our results remain robust to these changes in the computation of SRISK measure.

[29]In the robustness, we also consider a 15 and 20 percentile cut-off and find similar results.

[30]We find that $\beta_1 + \beta_2$ is positive and statistically different from 0 at 1% significance level which confirms that banks respond the most to higher haircuts of securities issued by domestic, systemically important banks.

Yorulmazer (2007) and Farhi and Tirole (2012). Higher haircut gaps on risky bonds issued by systemically important banks (which are "too big to fail") in periphery countries incentivize the herding behavior by banks and exacerbate the "too many to fail" problem.

5.3 Cross-Pledging of Bank Bonds

Next, we exploit additional heterogeneity inside the domestic banking sectors to shed light on the types of banks' linkages that emerged as a reaction to LOLR policy. Does LOLR incentivize the cross-pledging of bank bonds? If high haircut gaps exacerbate the buildup of systemic risk through an increase in the interlinkages across banks, we would expect that as bank A pledges more of bank B bonds, also bank B increases the pledging of bank A bonds (i.e., cross-pledging of bank bonds between pairs of banks). Equation (8) presents our empirical set-up:

$$\begin{aligned}\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_{s}} = {} & \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1(\text{CrossPledge}_{s,b,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ & + \beta_2(\text{CrossPledge}_{s,b,t-1} \times \text{HaircutGap}_{s,t-1}) + \\ & + \beta_3(\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \beta_4\text{HaircutGap}_{s,t-1} + \\ & + \gamma_1(\text{CrossPledge}_{s,b,t-1} \times \text{Domestic}_{s,b}) + \gamma_2\text{CrossPledge}_{s,b,t-1} + \\ & + \gamma_3\text{Domestic}_{s,b} + \delta X_{s,t-1} + \epsilon_{s,b,t}\end{aligned} \tag{8}$$

We define the categorical variable $\text{CrossPledge}_{s,b,t-1}$ as 1 if the bank that issues the security s has pledged bonds issued by the bank b at time $t-1$. If the cross-pledging does not occur, we define the $\text{CrossPledge}_{s,b,t-1}$ variable as 0.[31] Table 7 reports the results. LOLR through higher haircut gaps stimulates banks to pledge securities issued by (other) domestic banks. The effects are particularly strong for the pledging of securities issued by banks which also pledge bonds issued by the pledging bank. This increase in the cross-holding concentration via direct cross-pledging of bank bonds between pairs of banks is further consistent with the systemic bailout "too many to fail" theory (Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012). Following Elliott et al. (2014), our findings on increased cross-

[31] Results are robust to defining this variable contemporaneously or using lags other than $t-1$ (not reported).

pledging of bank debt in response to higher haircut gaps are also consistent with integration motives (deeper relationships with each counterparty) as opposed to diversification motives (more counterparties).

Our findings closely relate to Goldstein et al. (2020) who show that bank homogeneity amplifies the fragility of the financial sector. In Goldstein et al. (2020), banks are indirectly interconnected through the asset markets and their similarities exacerbate their selling behavior and, thus, increase the probability of bank runs. Our paper documents an additional layer of (direct) interconnectedness triggered by the LOLR policy. Higher haircut gaps increase the direct linkages across banks.

6 Systemic Risk: ECB Institutional Rules

A key insight from the full sample analysis is that LOLR policy provides incentives for banks to pledge bonds with higher haircut gaps issued by other similar banks or systemically important banks. In this section, we examine the effect of haircut gaps on systemic risk using two respective identification strategies introduced in Section 3.3. We revisit the estimation results from Section 5 by focusing on the two targeted identification strategies using ECB institutional rules.

Tables 8–11 are organized as follows. Columns (1)–(3) exploit the first identification strategy that uses non-linear 'kinks and jumps' in the haircut gap with respect to the rating. This identification relies on the fact that the market haircuts react to every notch downgrade, with larger increases in haircuts for downgrades at the bottom tier of the investment grade rating. Instead, for the ECB, within a security class, the haircut only jumps once from A- to BBB+. There are no other jumps between AAA and A- (low risk) nor between BBB+ and BBB- (high risk). This institutional feature allows us to empirically test the hypothesis that following a one notch downgrade, the pledging of domestic bonds with the ECB increases by more at notches characterized by a larger jump in the haircut gap. Columns (4)–(5) report estimates of the second identification approach. Here, we narrow down the sample to the securities at the A- rating cliff and we exploit the variation in the haircut gap following a one notch downgrade. We get the identification from exploiting the fact that the ECB moves to the next BBB+ haircut notch only if the downgrade affects the first best rating while private market tend to react to any downgrade. As a result a one notch downgrade from the A- is associated with a higher haircut gap if it does not move ECB valuation (the rating is non-binding for the ECB).

In Table 8, we proxy for bank similarity with the correlation of bank bond prices between the pledging and issuing bank. Similarly to the full sample results, the estimates attribute the increased dependence on ECB funding to the securities issued by similar banks. Table 9 highlights the essential role of domestic bonds. Overall, the results for domestic bonds are very similar to the findings in the full sample despite the large drop in the number of observations due to sample restrictions. Within domestic banks, we further differentiate the effect of LOLR policy between core and peripheral Europe. Table 10 supports our full sample evidence that the results are driven by the pledging of domestically issued bank bonds in the distressed periphery. The findings lend additional support to the unintended effect of the haircut gap channel of LOLR policy on the buildup of interconnectedness within the national banking sector in peripheral Europe. Finally, Table 11 reports the heterogeneous effects for bonds issued by different banks. We confirm that within domestically issued bank bonds, the bonds issued by systemically important banks drive the overall effect.

Taken together, our results provide consistent evidence in support of the literature on information and peer monitoring (Freixas et al., 2000; Rochet and Tirole, 1996). Banks primarily increase pledging of securities associated with higher haircut gaps issued by similar banks. Moreover, the findings show that banks pledge more bonds issued by domestic systemically important banks with systemic bailout theories (Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012).

7 Systemic Risk: Additional Results

7.1 External validity: Sectors without LOLR access

In this section, we present the results of a placebo test. In particular, we analyze how the holdings of bank bonds react to the LOLR haircut gap differently for banks (sector with access to LOLR) versus other sectors such as pension and mutual funds, insurance firms and others (sectors without LOLR access):

$$\frac{\text{value held}_{s,c,i,t}}{\text{value outstanding}_s} = \alpha_s + \alpha_t + \alpha_r + \alpha_{c,i} + \beta_1(\text{HaircutGap}_{s,t-1} \times \text{LOLR access}_i) + \\ + \beta_2(\text{HaircutGap}_{s,t-1} \times \text{no LOLR access}_i) + \gamma(\text{LOLR access}_i) + \delta X_{s,t-1} + \epsilon_{s,c,i,t} \quad (9)$$

where the outcome variable represents the amount of security s held by sector i in country c at time t as a share of the total value outstanding of security s. Using sectoral holdings data, we compare the holdings of the same security s by sectors *with* LOLR access (banks) and sectors *without* LOLR access (pension funds, mutual funds, insurance companies, other financial institutions, non-financial institutions and households). In line with previous results we introduce security, time and rating group fixed effects as well as time-varying security controls. The sectoral level data do not allow to control for holding institution fixed effects. Instead, we introduce country-sector fixed effects.

The results summarized in Table 12 show that high haircut gaps are associated with higher demand for bank bonds only by institutions that have access to the LOLR facility. We find that only banks increase their holdings of other bank bonds with high haircut gaps. On the contrary, we find that the effect of haircut gaps on the holdings of bank bonds is negative for sectors that do not have access to the LOLR. These findings further corroborate the role of the haircut gap channel of LOLR policy.

7.2 vLTRO Period

In December 2011 and February 2012, the ECB offered banks an extraordinarily (3-year) long liquidity provision in form of the very long term refinancing operations (vLTRO). The ECB allotted a total of approximately EUR 1 trillion of funding – making the vLTRO the largest liquidity provision in the history of modern central banking.[32] Given that vLTRO provides banks with more favorable borrowing conditions from the LOLR, it can be considered as a more accommodative LOLR policy.

In this section, we investigate the effect of haircut gaps on bank bond pledging in the vLTRO period. We focus on the period 6 months +/- around LTRO introduction from June

[32] For more details, see Jasova et al. (2021).

2011 to June 2012.[33] To this end, we extend the baseline Equation (5) with an additional time dummy variable *Post* that takes the value of 1 in the post-LTRO period (December 2011 – June 2012) and 0 in the pre-LTRO period (June 2011 – November 2011). Specifically, we estimate the following equation:

$$\begin{aligned}\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1(\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b} \times \text{Post}_t) + \\ + \beta_2(\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}) + \beta_3(\text{HaircutGap}_{s,t-1} \times \text{Post}_t) + \\ + \beta_4 \text{HaircutGap}_{s,t-1} + \gamma_1 \text{Domestic}_{s,b} + \gamma_2(\text{Domestic}_{s,b} \times \text{Post}_t) + \delta X_{s,t-1} + \epsilon_{s,b,t}\end{aligned} \tag{10}$$

Table 13 summarizes the results. The positive and statistically significant estimate of the triple interaction coefficient (β_1) suggests that the effects of the haircut gap on the pledging of domestic bank bonds are stronger in times of more accommodative LOLR stance (vLTRO period).

7.3 Sovereign and Issuer Risk

We revisit our baseline results and show that they are not driven by banks' common exposure to sovereign risk. To this end, we expand our baseline regressions with issuer country-time fixed effects to control for sovereign risk. The estimates presented in Columns (1) and (5) of Table 14 confirm that our original findings are robust.

Next, we test whether the systemic risk effects of the haircut gap are robust to controlling for unobserved time-varying riskiness, liquidity or overall issuance of securities by the same issuer in each time period. For this purpose, we saturate our baseline regressions with issuer-time fixed effects (Columns (2) and (6) of Table 14) and even more granular ISIN-time fixed effects (Columns (3) and (7) of Table 14), which subsume security controls: residual maturity and bond price. These specifications also allow us to address the potential concern that a higher haircut gap could just reflect a higher issuer/security riskiness and, hence our results would merely capture risk-taking behavior by other banks. Our findings on the pledging effects of haircut gap are robust when controlling for time-varying issuer or security riskiness.

[33] We stop the sample before July 2012 to avoid the overlap with the announcement of the Outright Monetary Operations.

Moreover, to control for fundamentals of the bank which pledges securities to the LOLR, we introduce pledging bank-time fixed effects that absorb observable and unobservable time-varying pledging bank variation (Table 14 see Columns (4) and (8)). This specification allows us to control for time-varying security holdings and pledging behavior of banks. Our findings remain robust.

7.4 Further Robustness

Finally, we perform a battery of further robustness tests to corroborate our findings. Specifically, our findings are robust to alternative choices of the dependent variable, the sample construction, the proxy for systemically important banks and the measure of LOLR intervention.

First, we use sectoral holdings data to study whether our baseline results on increased pledging of domestic securities are also reflected in increased holdings. Online Appendix Table B1 reports results when estimating Equation (5) using as an outcome variable the value of securities held by banks as a share of the total value outstanding. The estimates confirm that the effect on bank holdings is consistent with that on pledging. Banks increase both holding and pledging of domestic securities associated with higher haircut gaps. This evidence is further illustrated in Online Appendix Figure B1 which shows that 75% of bonds are pledged within three months after the issuance (Panel (a)) and banks pledge over 90% of securities held (Panel (b)).

Second, our findings are robust to different data methodologies regarding the imputation of the private market haircuts. In our baseline analysis, we use private market haircuts imputed with the random forest technique.[34] We show that the results are also robust to the use of Bayesian Model Averaging (BMA) or simple linear regressions.[35] The rationale behind the use of imputed data is related to the potential concern that high haircut gap securities may be underrepresented in the private market haircut data because banks with access to the LOLR facilities can obtain larger liquidity against them from the central bank. These securities still appear in our dataset because they are used in the private market repo

[34]See Online Appendix A.

[35]See Online Appendix Table A1.

transactions by other financial institutions without access to the LOLR. Nevertheless, all our main results (e.g., domestic bank bonds, SRISK, cross-pledging) are also robust to the use of raw private market haircut data.[36]

Third, we show that our systemic risk results are consistent with a range of proxies for systemically important institutions. In addition to the complex measure of SRISK, we also repeat the analysis using the bank size and equity ratio as simple proxies of the banks' systemic importance.[37] Consistently with the SRISK results, we find economically and statistically strong effects on the pledging of bank securities issued by domestic large banks or low equity banks.

Fourth, we revisit the identification strategy on binding and non-binding downgrades using ratings instead of the haircuts.[38] This strategy isolates the effect of LOLR on banks' pledging behavior around a one notch downgrade from A- to BBB+ using a window of +/- 2 months around the event. As shown in Section 3.3, the ECB considers only the best rating across the four agencies and, hence, we distinguish between two types of downgrades. Non-binding downgrades increase the size of the haircut gap while binding downgrades decrease it. Thus, in this robustness analysis, we use a difference-in-difference research design and we define non-binding downgrades as *Treated* and binding downgrades as *Control*.[39] Consistent with our baseline results, we show that non-binding downgrades (treated) provide more incentives for banks to increase their pledging with the LOLR as opposed to binding downgrades. This robustness exercise presents an alternative way to validate the effects of the LOLR on banks' pledging without the direct use of haircuts.

Fifth, we show that our results are not driven by any specific country. In particular, the findings remain robust when we exclude one country at a time.[40]

[36]See Column (4) of Online Appendix Table A1 and Online Appendix Tables C1 and C2.

[37]We report results using bank size in Online Appendix Table B2 and equity ratio in Online Appendix Table B3. Similarly to the SRISK, we denote banks as systemically important if they belong to the 10% of the largest or the least capitalized banks in the respective country.

[38]While we do not always have the data on actual private market haircuts for all pledged securities, all ratings are available from ECB internal source (CSDB).

[39]The results are reported in Online Appendix Table B4.

[40]These results are available upon request.

8 Bank Bonds Issuance

So far, we have shown that in response to higher haircut gaps, banks increase their *demand* for bank-issued bonds. In this section we explore the *supply* side response to LOLR funding in the bank bond market. In other words, do higher haircut gaps also impact the decision to issue new securities? We investigate the issuance response in two ways. First, we start with a security level analysis where we focus on the events of new bank bond issuances. We estimate the following equation:

$$\log(\text{value issued})_{s,t} = \alpha_t + \alpha_r + \alpha_c + \beta \mathbb{E}_{t-1}(\text{HaircutGap}_{s,t}) + \gamma X_{s,t} + \epsilon_{s,t} \tag{11}$$

where $\log(\text{value issued})_{s,t}$ denotes the log value of security s issued at time t. We regress the issued value on the haircut gap measure of the security. Because the security is issued only at time t, previous levels of the haircut gap cannot be observed. We address this issue by constructing an expected value of the haircut gap. To compute the ECB haircut, we rely on publicly available ECB haircut policy rules. We employ the machine learning algorithm to predict the private market haircut using the issuer rating as of $t-1$ along with the actual maturity, asset type and coupon type of the security s.[41] We progressively saturate the specification with control variables (log of bond prices and residual maturity at the time of the issuance) and fixed effects (time, rating and country of issuer).

The second approach collapses the data at the bank-time level. We construct the outcome variable as the log value of total issued debt outstanding of bank b at time t. This strategy allows us to distinguish between new bond issuances which simply replace maturing debt and issuances that increase the bank's overall borrowing from the bond market. We estimate the effect of the haircut gap on the bank-level amount of debt outstanding using the following specification:

$$\log(\text{value outstanding})_{b,t} = \alpha_t + \alpha_r + \alpha_b + \beta \text{HaircutGap}_{b,t-1} + \epsilon_{b,t} \tag{12}$$

$\text{HaircutGap}_{b,t-1}$ is the bank-level haircut gap constructed as average security level haircut

[41] See Online Appendix A.

gap weighted by the value outstanding. In this case, as there are (existing) observed haircut gaps for other securities outstanding of bank b, we do not need to predict the bank-level haircut gap. We control for issuing bank and issuer rating fixed effects.

Table 15 summarizes both types of issuance analyses. In both cases, the results reveal higher supply of bank bonds in response to higher haircut gaps. Panel (a) focuses on the sample of 8,242 newly issued ISINs in the security-level analysis. We start by controlling for the log of bond prices and residual maturity ($X_{s,t}$) and the month of the issuance fixed effects (α_t) and we progressively saturate the model with additional fixed effects. As shown in Columns (2)–(4), the coefficient's magnitude becomes larger when controlling for the rating and country of issuer fixed effects. As shown in Column (4), a 10 percentage point increase in the haircut gap is associated with the 24.3% increase in the value of bond issuance.

Table 15 Panel (b) reports the bank-level analysis which also controls for a potentially confounding effect of new issuances that replace the maturing bonds. Positive and statistically significant coefficients in Panel (b) suggest that the issuance of new debt goes beyond the replacement of maturating debt. Higher haircut gaps incentivize banks to issue additional bank bonds and increase the total dependence on bond market financing. A 10 percentage point increase in the haircut gap is associated with the 5.4% increase in the amount of bank debt outstanding.

Figure 7 further corroborates the evolution of new bank bond issuances over time. In line with the empirical estimates, we observe high instances of bank bond issuances at times of high haircut gaps, especially in the case of peripheral banks, where the haircut gaps reached the highest levels.

9 Conclusion

This paper examines whether and how LOLR policy affects bank interconnectedness, thereby affecting systemic risk. Our analysis uses a novel micro-level dataset that links the securities pledged by banks to obtain LOLR funding with the haircuts applied by the LOLR and the private repo markets. We investigate the haircut gap channel of the LOLR, i.e. the difference between the haircut applied by the private market and the central bank for securities that banks pledge as collateral in repo operations. For identification, our analysis focuses on the provision of liquidity by the European Central Bank (ECB) in the period 2009–2015. The Eurozone offers an ideal setting to study the implications of LOLR policy for three reasons: i) banks are at the core of the financial system in Europe; ii) during the Global Financial Crisis and The European Sovereign Debt Crisis the ECB expanded its liquidity provision to an unprecedented scale and scope; iii) the extraordinary availability of ECB and private market data allows us to properly analyze the haircut gap channel of LOLR.

We find that LOLR policy incentivizes banks to increase their pledging of bonds associated with higher haircut gaps. This effect is stronger for bonds issued by other banks than for sovereigns. In particular, banks increase the pledging of bonds issued by interconnected banks, consistent with theories of interbank monitoring (e.g., Rochet and Tirole, 1996) rather than risk sharing (e.g., Allen and Gale, 2000, 2007). We show that interconnectedness is stronger across similar banks, i.e. domestic banks and banks with correlated bond prices, consistent with segmented markets. Within domestic banks, high haircut gaps further increase the pledging of bonds issued by systemically important banks and also the direct cross-pledging of bank bonds, consistent with theories of bailout expectations in the event of a systemic crisis (e.g., Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012). Further, higher haircut gaps only incentivize banks (with LOLR access), not other sectors (without LOLR access), to increase bank bond holdings. Finally, and consistent with an increase in the demand for bank bonds with higher haircut gaps, we also document that LOLR policy stimulates their issuance of these bonds by banks.

All in all, our results uncover an important role for bank bonds as a source of collateral for other banks and show that LOLR policy increases bank interconnectedness, by encouraging the cross-holding of bank debt. Taken together, we show a new haircut channel of monetary operations, which encourages an increase in the concentration of bank risk within the banking sector. This potentially adverse effect of LOLR policies should ultimately be evaluated against other positive effects, including the beneficial effects of LOLR operations in terms of absorbing illiquidity risk and supporting bank credit to the private sector previously identified in the literature and the positive effect on the issuance of bank bonds uncovered in this paper.

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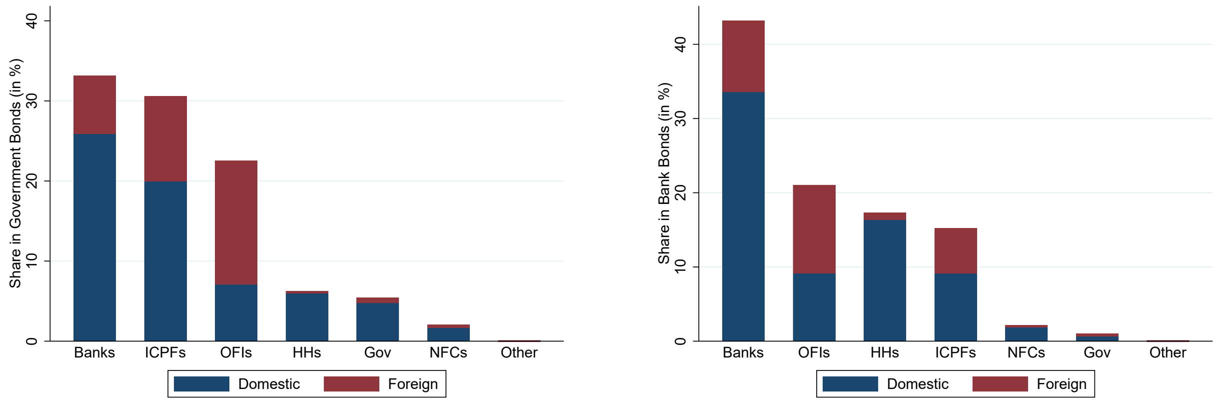
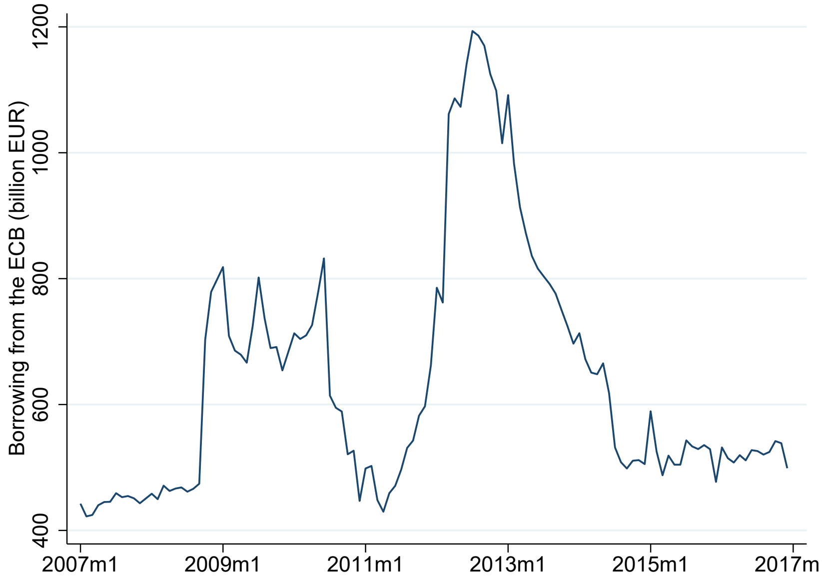
Figure 1: Security holdings by sectors

(a) Main holders of government bonds (b) Main holders of bank bonds



Notes: This figure shows the holders of government and bank securities. We divide the holdings across key institutional sectors: banks, insurance companies and pension funds (ICPFs), other financial institutions (OFIs), households (HH), central government (Gov), non-financial corporations (NFC) and Other. A security is denoted as Domestic if the pledging and issuing institution have the same country of location, and as Foreign otherwise. The values are reported in percent to total value outstanding. All reported figures refer to Q1 2014. Source: Security Holdings Statistics.

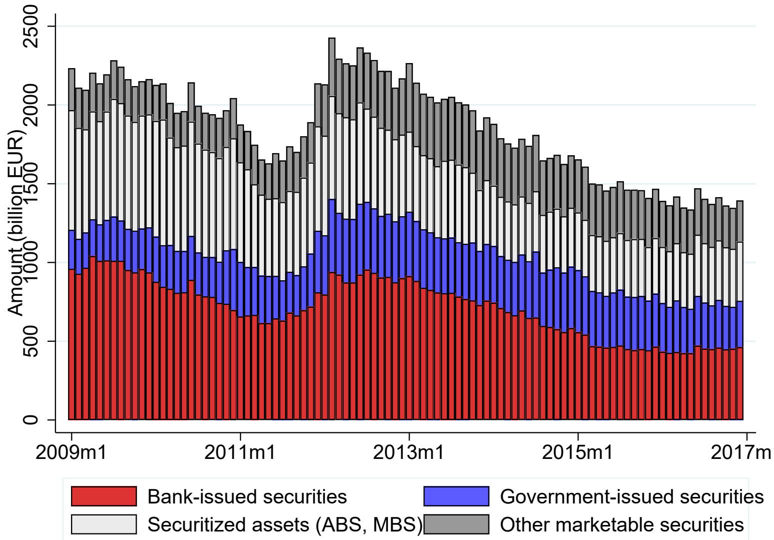
Figure 2: ECB liquidity provisions



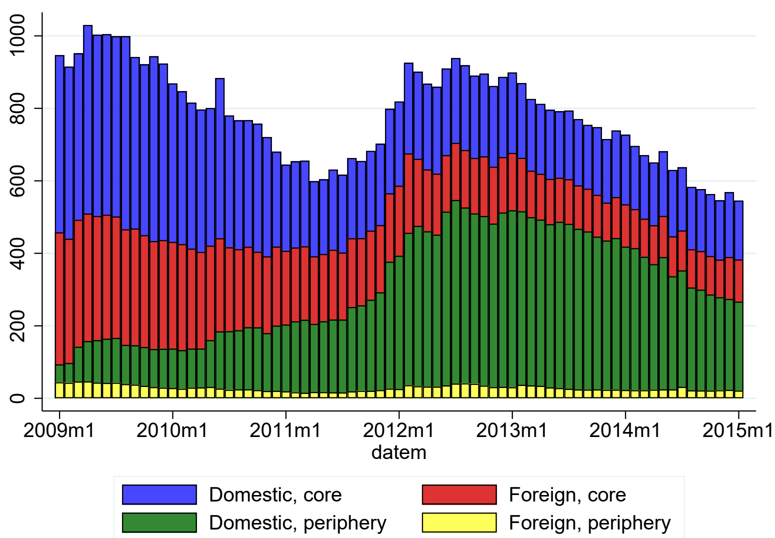
Notes: This figure shows the total bank borrowing from the ECB. The borrowing is a sum of liquidity received by weekly main refinancing operations (MRO) and all longer-term refinancing operations (all LTRO and targeted-LTRO facilities) of all banks in the euro area. Reported in billion EUR. Source: ECB Market Operations Database.

Figure 3: Collateral pledging with the ECB

(a) All collateral by security type



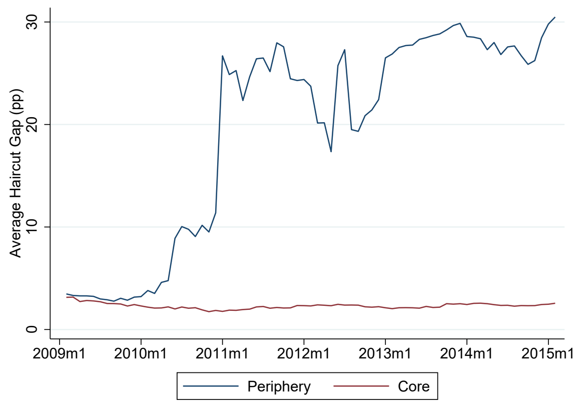
(b) Bank bonds



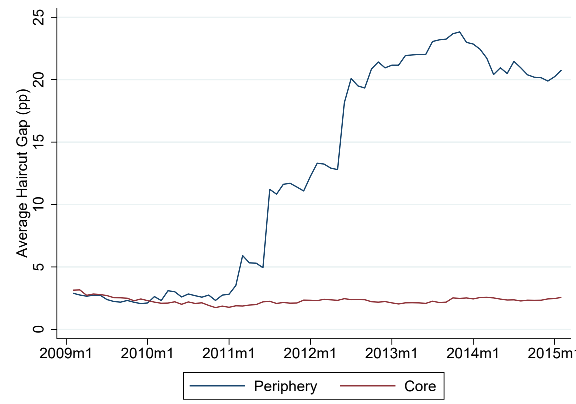
Notes: This figure summarizes the securities pledged as collateral with the ECB by all banks in the euro area. Panel (a) summarizes the composition of marketable securities; Panel (b) displays the composition of bank-issued securities across Core and Periphery euro area countries. Periphery denotes Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while Core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands. A bank bond is denoted as Domestic if the pledging and issuing banks have the same country of location, and as Foreign otherwise. Both panels are reported in book values in billion EUR.

Figure 4: Average haircut gap for securities issued in core and periphery

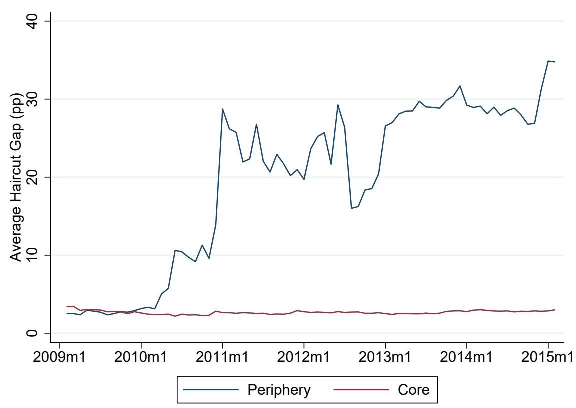
(a) Bank and government securities (All countries)



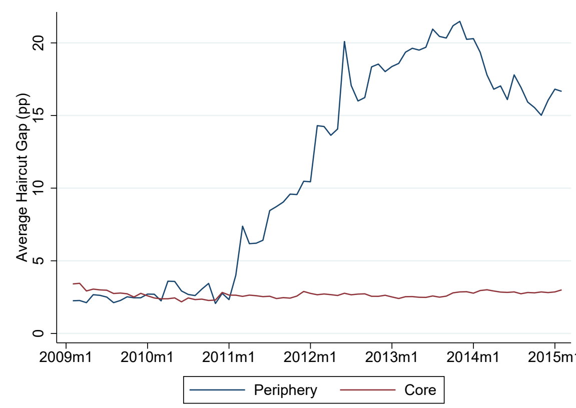
(b) Bank and government securities (Excl. Greece)



(c) Bank securities (All countries)

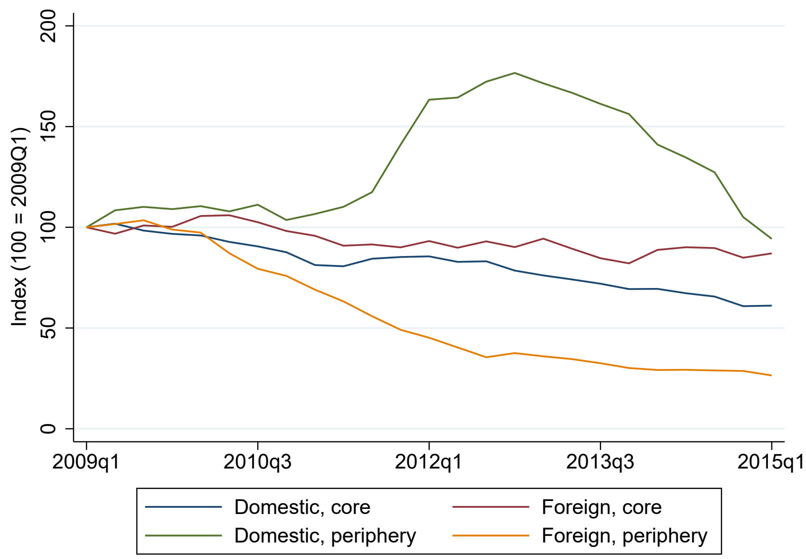


(d) Bank securities (Excl. Greece)



Notes: This figure shows the evolution of the haircut gap over time across periphery and core countries. Periphery denotes Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while Core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands. The average haircut gap is reported in percentage points on the vertical axis.

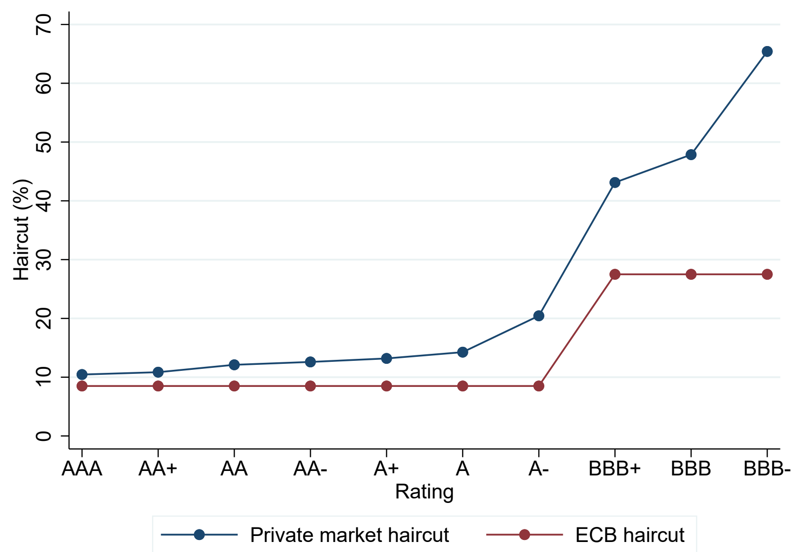
Figure 5: Holdings of bank bonds



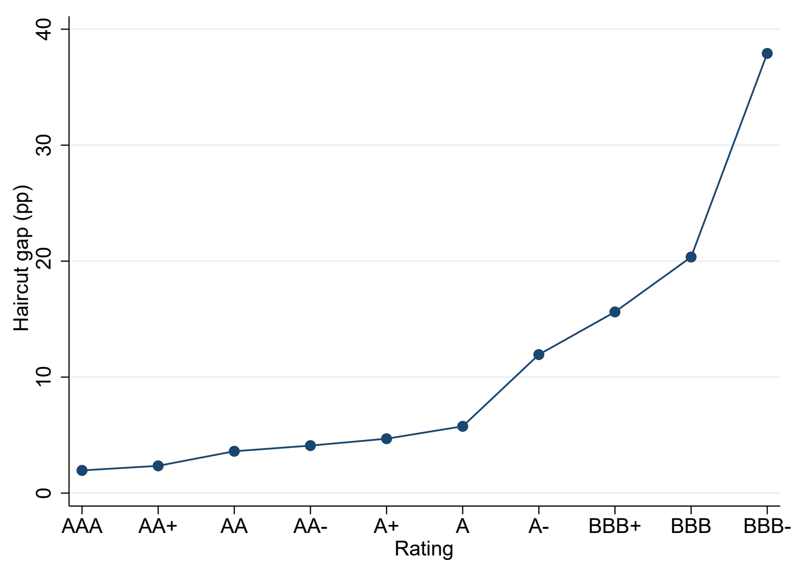
Notes: This figure summarizes the holdings of bank bonds. A bank bond is denoted as Domestic if the pledging and issuing banks have the same country of location, and as a Foreign otherwise. Furthermore, we divide the pledging banks into two categories: Periphery and Core based on their location. Periphery countries denote Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while Core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands. All series are indexed to Q1 2009.

Figure 6: Haircuts and haircut gap

(a) Private market vs. ECB haircuts

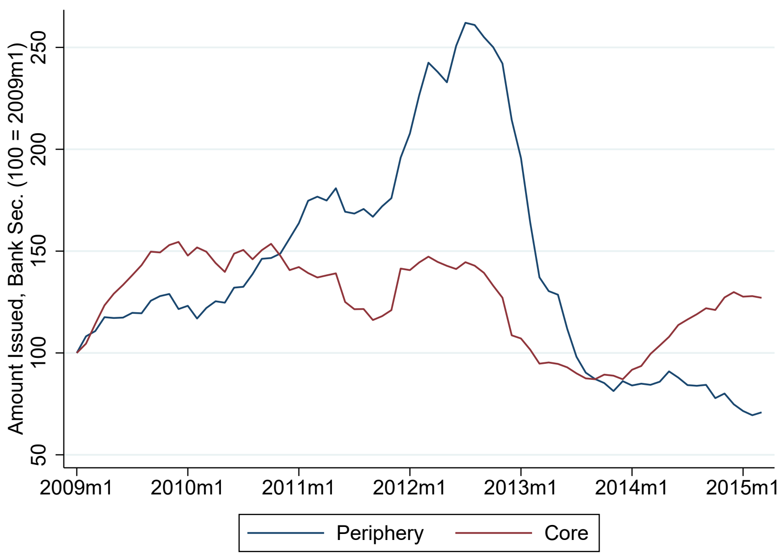


(b) Haircut gap



Notes: This figure illustrates the identification strategies using the ECB institutional rules. The figures plot haircuts and haircut gaps for a representative asset class: uncovered bank bonds with residual 1-3 years maturity and fixed coupon. Panel (a) shows the average haircuts applied by the ECB and private market for each rating notch. Panel (b) summarizes the non-linear profile of the haircut gap with respect to different ratings.

Figure 7: Issuances of bank bonds



Notes: This figure summarizes the issuances of bank bonds. We divide the pledging banks into two categories: Periphery and Core based on their location. Periphery countries denote Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while Core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands. Issuances are reported as a 12-month moving average. All series are indexed to Q1 2009.

Table 1: Summary statistics

		N	mean	sd
Bank-Security-Time level				
Haircut gap	in percentage points	3,757,580	6.06	11.97
Private market haircut	in %	3,757,580	11.98	14.86
ECB haircut	in %	3,757,580	5.91	5.96
Value pledged	in % of value outstanding	3,757,580	5.16	18.50
Domestic	1=yes, 0=no	3,757,580	0.60	0.40
Periphery	1=yes, 0=no	3,757,580	0.23	0.42
Cross pledging	1=yes, 0=no	2,748,282	0.16	0.37
SRISK	1=yes, 0=no	2,586,886	0.27	0.44
Correlation of bond prices	correlation coefficient	1,112,014	0.28	0.43
Security-Time level				
Haircut gap	in percentage points	477,104	5.19	10.00
Private market haircut	in %	477,104	11.79	12.53
ECB haircut	in %	477,104	6.60	5.27
Value pledged	in % of value outstanding	477,104	41.40	39.40
Residual maturity	in years	477,104	3.56	4.11
Bond price	log	477,104	-0.008	0.112
Rating	numerical scale	477,104	4.1	2.7
Issuance	in mil EUR	8,245	445.09	1,273.63

Notes: This table show the summary statistics of key variables for the sample period Jan 2009 – March 2015.

Table 2: Haircut gap: government vs. bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{HaircutGap}_{s,t-1} \times \text{Bank Bonds}_s$	0.00634***	0.00567***	0.00307***
	(0.000780)	(0.000788)	(0.000848)
$\text{HaircutGap}_{s,t-1}$	0.00369***	0.00295***	0.00522***
	(0.000308)	(0.000347)	(0.000594)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	3,757,583	3,757,580	3,757,580
R^2	0.867	0.867	0.867

Notes: This table presents coefficients from the regressions related to the pledging of both government and bank bonds, as described in Equation (3). The categorical variable Bank Bond takes the value of 1 if the bond is issued by a bank, and 0 if it is issued by the government. Controls include log values of security residual maturity and price. Full sample of government and bank bonds. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 3: Systemic risk: bond price correlation
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{HaircutGap}_{s,t-1} \times \text{Correlation}_{s,b,t-1}$	0.0293***	0.0291***	0.0291***
	(0.00354)	(0.00354)	(0.00353)
$\text{HaircutGap}_{s,t-1}$	0.00278	0.00284	0.00153
	(0.00194)	(0.00196)	(0.00174)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	1,112,014	1,112,014	1,112,014
R^2	0.812	0.812	0.812

Notes: This table presents the coefficients from the regressions related to the pledging of bank bonds, as described in Equation (4). Correlation denotes the correlation coefficient between the bond prices of the pledging and issuing banks. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Systemic risk: domestic vs. foreign
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
HaircutGap$_{s,t-1}$ × Domestic$_{s,b}$	0.0169***	0.0159***	0.0151***
	(0.00146)	(0.00146)	(0.00147)
HaircutGap$_{s,t-1}$ × Foreign$_{s,b}$	0.0015	0.0004	-0.0004
	(0.00133)	(0.00133)	(0.00135)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	2,662,362	2,662,362	2,662,362
R^2	0.869	0.869	0.869

Notes: This table presents coefficients from regressions related to the pledging of bank bonds, as described in Equation (5). We split the securities issued by banks in two categories: Domestic and Foreign. A security is denoted as Domestic if the pledging and issuing banks have the same country of location, and as Foreign otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Systemic risk: core vs. periphery
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{Periphery}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0170***	0.0170***	0.0168***
	(0.00173)	(0.00175)	(0.00181)
$\text{Periphery}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00343*	0.00300	0.00175
	(0.00185)	(0.00186)	(0.00188)
$\text{Core}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00352	0.00222	0.000382
	(0.00318)	(0.00341)	(0.00343)
$\text{Core}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00194	0.000946	-0.0000805
	(0.00139)	(0.00142)	(0.00146)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	2,791,549	2,675,861	2,662,362
R^2	0.862	0.869	0.869

Notes: This table presents coefficients from regressions related to pledging of bank bonds, as described in Equation (6). A security is denoted as Domestic if the pledging and issuing banks have the same country of location, and as Foreign otherwise. Furthermore, we divide the pledging banks into two categories: Periphery and Core based on their location. Periphery denotes Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while Core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Systemic risk: high SRISK banks
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{Domestic}_{s,b} \times \text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}$	0.0225***	0.0221***	0.0224***
	(0.00384)	(0.00384)	(0.00385)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00877**	0.00914***	0.00899***
	(0.00344)	(0.00344)	(0.00344)
$\text{SRISK}_{b,t-1} \times \text{HaircutGap}_{s,t-1}$	-0.00943***	-0.00925***	-0.0101***
	(0.00220)	(0.00220)	(0.00222)
$\text{HaircutGap}_{s,t-1}$	0.00239	0.00121	0.00114
	(0.00168)	(0.00169)	(0.00167)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	2,586,886	2,586,886	2,586,886
R^2	0.872	0.872	0.872

Notes: This table presents coefficients from regressions related to pledging of bank bonds, as described in Equation (7). SRISK takes the value of 1 if the issuing bank's SRISK ratio is in the top 10% of the SRISK ratios of all banks in the respective country, and 0 otherwise. Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Systemic risk: bond cross-pledging
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{CrossPledge}_{s,b,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0566***	0.0581***	0.0577***
	(0.00708)	(0.00720)	(0.00727)
$\text{CrossPledge}_{s,b,t-1} \times \text{HaircutGap}_{s,t-1}$	-0.0148**	-0.0176***	-0.0171***
	(0.00614)	(0.00624)	(0.00630)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00392	0.00508*	0.00556**
	(0.00264)	(0.00273)	(0.00277)
$\text{HaircutGap}_{s,t-1}$	0.000849	-0.00000507	-0.00103
	(0.00136)	(0.00138)	(0.00143)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	2,748,282	2,633,826	2,621,815
R^2	0.863	0.869	0.870

Notes: This table presents coefficients from regressions related to the pledging of bank bonds, as described in Equation (8). The categorical variable CrossPledge takes the value of 1 if the bank that issues the security s has pledged bonds issued by bank b at time $t-1$, and 0 otherwise. Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: Systemic risk: bond price correlation
Restricted sample of bank bonds: ECB institutional rules

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	Strategy 1: Kinks and Jumps			Strategy 2: Binding Downgrades	
	(1)	(2)	(3)	(4)	(5)
$\text{HaircutGap}_{s,t-1} \times \text{Correlation}_{s,b}$	0.0250*	0.0247*	0.0278**	0.0965***	0.0969***
	(0.0139)	(0.0139)	(0.0134)	(0.0253)	(0.0253)
$\text{HaircutGap}_{s,t-1}$	-0.0163**	-0.0153**	-0.0149***	-0.0403***	-0.0491***
	(0.00660)	(0.00671)	(0.00573)	(0.0114)	(0.0116)
Controls	No	Yes	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes	Yes	Yes
Rating group FE	No	No	Yes	-	-
N	46,089	46,089	46,089	17,210	17,210
R^2	0.891	0.891	0.891	0.943	0.943

Notes: This table presents the coefficients from the regressions related to pledging of bank bonds, as described in Equation (4) for the two identification strategies based on the ECB institutional rules. Correlation denotes the correlation coefficient between the bond prices of pledging and issuing banks. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 9: Systemic risk: domestic vs. foreign
Restricted sample of bank bonds: ECB institutional rules

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	Strategy 1: Kinks and Jumps			Strategy 2: Binding Downgrades	
	(1)	(2)	(3)	(4)	(5)
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}$	0.0167***	0.0170***	0.0160***	0.0263***	0.0172***
	(0.00552)	(0.00550)	(0.00569)	(0.00662)	(0.00632)
$\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,b}$	-0.0129**	-0.0125**	-0.0136***	0.00172	-0.00638
	(0.00514)	(0.00518)	(0.00511)	(0.00590)	(0.00572)
Controls	No	Yes	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes	Yes	Yes
Rating group FE	No	No	Yes	-	-
N	137,587	137,587	137,587	42,130	42,130
R^2	0.891	0.891	0.891	0.925	0.925

Notes: This table presents coefficients from regressions related to the pledging of bank bonds, as described in Equation (5) for the two identification strategies based on the ECB institutional rules. We split the securities issued by banks in two categories: Domestic and Foreign. A security is denoted as Domestic if the pledging and issuing banks have the same country of location, and as Foreign otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 10: Systemic risk: core vs. periphery
Restricted sample of bank bonds: ECB institutional rules

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	Strategy 1: Kinks and Jumps			Strategy 2: Binding Downgrades	
	(1)	(2)	(3)	(4)	(5)
$\text{Periphery}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0162**	0.0165***	0.0155**	0.0471***	0.0376***
	(0.00629)	(0.00627)	(0.00655)	(0.00750)	(0.00710)
$\text{Periphery}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}$	-0.00846	-0.00793	-0.00902	-0.0116	-0.0178
	(0.00669)	(0.00668)	(0.00673)	0.00440	0.00437
$\text{Core}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00676	0.00720	0.00562	0.00440	0.00437
	(0.0138)	(0.0138)	(0.0138)	(0.00612)	(0.00609)
$\text{Core}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}$	-0.0121**	-0.0117**	-0.0128**	-0.0816***	-0.0860***
	(0.00587)	(0.00591)	(0.00580)	(0.0190)	(0.0190)
Controls	No	Yes	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes	Yes	Yes
Rating group FE	No	No	Yes	-	-
N	137,587	137,587	137,587	42,130	42,130
R^2	0.891	0.891	0.891	0.925	0.925

Notes: This table presents the coefficients from the regressions related to the pledging of bank bonds, as described in Equation (6) for the two identification strategies based on the ECB institutional rules. A security is denoted as Domestic if the pledging and issuing banks have the same country of location, and as Foreign otherwise. Furthermore, we divide the pledging banks into two categories: Periphery and Core based on their location. Periphery denotes Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while Core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 11: Systemic risk: high SRISK banks
Restricted sample of bank bonds: ECB institutional rules

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	Strategy 1: Kinks and Jumps			Strategy 2: Binding Downgrades	
	(1)	(2)	(3)	(4)	(5)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1} \times \text{SRISK}_{s,t-1}$	0.0387**	0.0391**	0.0391**	0.0481*	0.0449*
	(0.0173)	(0.0173)	(0.0173)	(0.0253)	(0.0255)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00249	0.00225	0.00225	-0.0129	-0.0108
	(0.0112)	(0.0112)	(0.0112)	(0.0240)	(0.0242)
$\text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}$	-0.0227**	-0.0235**	-0.0231**	-0.0013	0.0045
	(0.00984)	(0.00985)	(0.00986)	(0.0140)	(0.0156)
$\text{HaircutGap}_{s,t-1}$	0.000276	0.00110	0.0000760	-0.0001	-0.0145
	(0.00537)	(0.00539)	(0.00532)	(0.0138)	(0.0153)
Controls	No	Yes	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes	Yes	Yes
Rating group FE	No	No	Yes	-	-
N	129,911	129,911	129,911	33,242	33,242
R^2	0.896	0.896	0.896	0.9331	0.9331

Notes: This table presents the coefficients from the regressions related to pledging of bank bonds, as described in Equation (7) for the two identification strategies based on the ECB institutional rules. SRISK takes the value of 1 if the issuing bank's SRISK ratio is in the top 10% of SRISK ratios of all banks in the respective country, and 0 otherwise. Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 12: External validity: Bank bond holdings across sectors

	$\frac{\text{value held}_{s,c,i,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{HaircutGap}_{s,t-1} \times \text{LOLR access}_i$	0.0480***	0.0463***	0.0535***
	(0.0062)	(0.0062)	(0.0066)
$\text{HaircutGap}_{s,t-1} \times \text{no LOLR access}_i$	-0.0105***	-0.0125***	-0.0086***
	(0.0027)	(0.0028)	(0.0032)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Country-Sector FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	861,644	861,644	849,884
R^2	0.6734	0.6734	0.6748

Notes: This table presents the coefficients from the regressions related to the holdings of bank bonds across sectors, as described in Equation (9). LOLR access denotes the banking sector. No LOLR access denotes other sectors (i.e, pension funds, mutual funds, insurance companies) that cannot borrow from the LOLR facilities. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 13: Systemic risk: domestic vs. foreign
pre- and post- vLTRO

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b} \times \text{Post}_t$	0.0138***	0.0128***	0.0124***
	(0.00483)	(0.00483)	(0.00484)
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}$	0.0180***	0.0186***	0.0185***
	(0.00466)	(0.00466)	(0.00466)
$\text{HaircutGap}_{s,t-1} \times \text{Post}_t$	-0.0025	-0.0025	-0.0019
	(0.00268)	(0.00268)	(0.00278)
$\text{HaircutGap}_{s,t-1}$	-0.0104***	-0.0104***	-0.0096***
	(0.00310)	(0.00311)	(0.00308)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	541,293	541,293	541,293
R^2	0.875	0.875	0.875

Notes: This table presents the coefficients from the regressions related to the pledging of bank bonds, as described in Equation (10). Post_t takes the value of 1 in the post-LTRO period (December 2011 – June 2012), and 0 in the pre-LTRO period (June 2011– November 2011). Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 14: Systemic Risk: robustness to fixed effects
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\text{Domestic}_{s,b} \times \text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}$					0.0223***	0.0198***	0.0219***	0.0117**
					(0.00394)	(0.00448)	(0.00548)	(0.00528)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0157***	0.0181***	0.0144***	0.0115***	0.0100***	0.0136***	0.0110**	0.0115***
	(0.00242)	(0.00265)	(0.00299)	(0.00294)	(0.00349)	(0.00391)	(0.00454)	(0.00440)
$\text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}$					-0.0117***	-0.00859***		
					(0.00239)	(0.00323)		
$\text{HaircutGap}_{s,t-1}$	-0.000523	0.00259			0.000630	0.00231		
	(0.00146)	(0.00178)			(0.00183)	(0.00239)		
Controls	Yes	Yes	Yes	-	Yes	Yes	Yes	-
Issuer Country-Time FE	Yes	-	-	-	Yes	-	-	-
ISIN FE	Yes	Yes	-	-	Yes	Yes	-	-
Issuer-Time FE	No	Yes	-	-	No	Yes	-	-
Bank FE	Yes	Yes	Yes	-	Yes	Yes	Yes	-
Rating group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ISIN-Time FE	No	No	Yes	Yes	No	No	Yes	Yes
Bank-Time FE	No	No	No	Yes	No	No	No	Yes
N	2,662,332	2,617,669	2,483,341	2,468,470	2,586,856	2,582,796	2,412,072	2,397,216
R^2	0.871	0.873	0.900	0.941	0.874	0.876	0.901	0.942

Notes: This table presents the coefficients from the regressions related to the pledging of bank bonds, as described in Equation (7) when controlling for different fixed effects. S Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 15: Issuance of bank bonds

Panel (a): Security-level analysis

	$\log(\text{value issued})_{s,t}$			
	(1)	(2)	(3)	(4)
$\mathbb{E}_{t-1}(\text{HaircutGap}_{s,t})$	0.845***	1.378***	2.633***	2.426***
	(0.153)	(0.352)	(0.398)	(0.368)
Controls	Yes	Yes	Yes	Yes
Date issued FE	Yes	Yes	Yes	Yes
Rating group FE	No	Yes	-	-
Rating FE	No	No	Yes	Yes
Country of issuer FE	No	No	No	Yes
N	8,245	8,245	8,243	8,242
R^2	0.0580	0.108	0.142	0.282

Panel (b): Bank-level analysis

	$\log(\text{value outstanding})_{b,t}$			
	(1)	(2)	(3)	(4)
$\text{HaircutGap}_{b,t-1}$	0.274***	0.774***	0.579***	0.537***
	(0.0480)	(0.0552)	(0.0874)	(0.0924)
Time FE	No	Yes	Yes	Yes
Issuing bank FE	Yes	Yes	Yes	Yes
Rating group FE	No	No	Yes	-
Rating FE	No	No	No	Yes
N	25,212	25,212	23,327	20,599
R^2	0.954	0.955	0.955	0.963

Notes: This table presents the coefficients from the regressions related to the issuance of bank bonds as described in Equations (11) and (12). Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Online Appendix

Systemic Risk and Monetary Policy: The Haircut Gap Channel of the Lender of Last Resort

A Machine Learning: Private Market Haircuts

To provide a full picture of the haircut gaps for all securities pledged with the ECB, we perform imputation of private market haircuts using machine learning. In the baseline version, we use a random forest technique.

The random forest works by aggregating the predictions made by multiple decision trees of different depth. The strategy consists of the following steps. First, the decision trees in the forest are trained on bootstrapped training datasets. For the decision tree splits, the algorithm considers a random sample of predictors. Based on the institutional background of the repo markets, our predictors include asset class, ratings (respective rating agencies Fitch, Moody's, S&P, DBRS as well as their combinations), coupon and residual maturity. Finally, the procedure aggregates the prediction of each tree.

In the baseline, we set the number of trees to 100 and the number of variables tried at each split to 13. The terminal node size is 5. This setting allows us to explain 99.06% of the variance. We evaluate the performance by the out-of-bank (OOB) dataset to measure the out-of-sample prediction proprieties. The OOB error rate is 5.38 and the root mean squared error (RMSE) is 2.32. According to the prediction algorithm, we validate that all rating changes have significant impact on the private market haircut valuation.

The main benefits of implementing a random forest is its agnostic nature as well as the ability to work with correlated regressors. Nevertheless, we repeat the prediction exercise using a Bayesian Model Averaging (BMA) technique and simple linear regressions.

Similarly to the random forest, the BMA estimated regression models with different subsets of variables. Again, we start by considering a similarly comprehensive set of variables (while unlike random forest some combinations are dropped due to collinearity). BMA uses model composition Markov Chain Monte Carlo algorithm to walk through the models with the highest posterior model probabilities. We use a uniform model prior (i.e., each model has the same probability) and unit information g-prior (the prior that all regression coefficients equal zero has the same weight as one observation in the data). The number of models visited is 186,913 and the RMSE is 3.7.

The regression result of all prediction techniques as well as original raw sample are reported in Online Appendix Table A1.

Table A1: Robustness to different haircut gap measures and sample construction

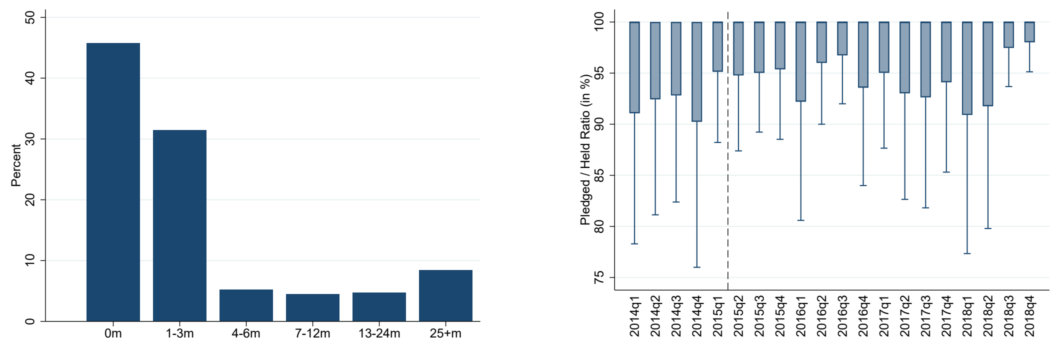
	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$			
	Random Forest (Baseline)	BMA	Linear regression	Raw data
	(1)	(2)	(3)	(4)
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}$	0.0151^{***}	0.0163^{***}	0.0126^{***}	0.0260^{***}
	(0.00147)	(0.0011)	(0.0012)	(0.0060)
$\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,b}$	-0.0004	0.0019^{*}	0.0012	-0.0167^{***}
	(0.00135)	(0.0010)	(0.0010)	(0.0039)
Controls	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes	Yes
Rating group FE	Yes	Yes	Yes	Yes
N	2,662,362	1,985,012	2,111,269	150,567
R^2	0.869	0.838	0.839	0.898

Notes: This table presents the coefficients from the regressions described in Equation (5). In Column (1), Random Forest denotes our baseline measure of the Haircut Gap. Columns (2) and (3) show robustness to different data imputation using Bayesian Model Averaging or Linear Regression, respectively. Column (4) reports the estimate for the raw sample. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

B Additional Tables and Figures

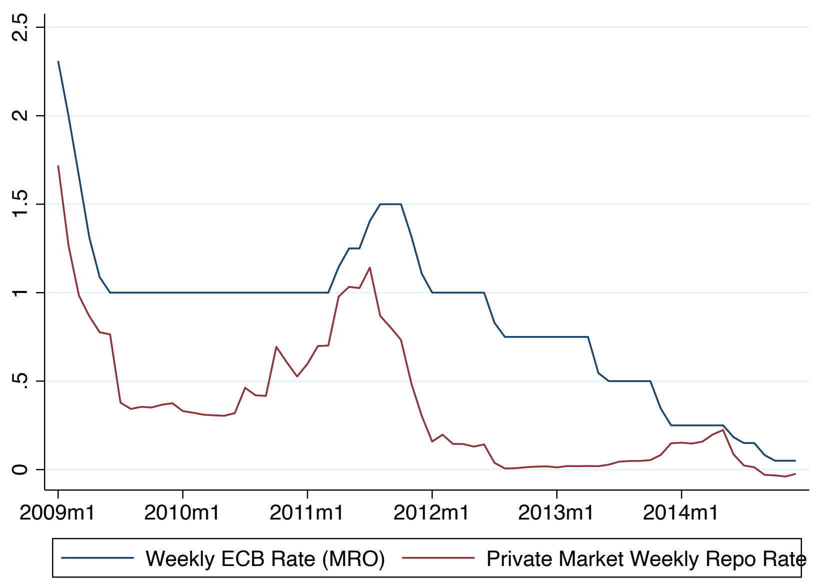
Figure B1: Pledging and holding

(a) Timing of pledging of newly issued bonds (b) Ratio of amount pledged to held



Notes: This figure shows the relationship between security holding and security pledging with the ECB. Panel (a) illustrates the timing of pledging after the security is issued. More than 75% of securities are pledged with the ECB within the first 3 months. Panel (b) shows the ratio of amount pledged to amount held at the cross-section of Eurozone banks over time. Vertical black dashed line denotes the end of our sample period. Sources: ECB MOPDB and SHS.

Figure B2: ECB liquidity provisions



Notes: This figure shows the evolution of the borrowing rates from the ECB (blue line) and the private repo market (red line). ECB rate is a weekly main refinancing operations (MRO) rate. Private market repo rate refers to the EUREPO rate reported by the panel of European banks to the European Money Markets Institute on repo transactions against the General Collateral. Rates are reported in percent.

Table B1: Robustness to different outcome variable and haircut gap measures

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$	$\frac{\text{value held}_{s,c,t}}{\text{value outstanding}_s}$
	Baseline (1)	(2)
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}$	0.0151***	
	(0.00147)	
$\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,b}$	-0.0004	
	(0.00135)	
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,c}$		0.0433***
		(0.0137)
$\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,c}$		-0.0103
		(0.0067)
Controls	Yes	Yes
Time FE	Yes	Yes
Country FE	-	Yes
Bank FE	Yes	No
ISIN FE	Yes	Yes
Rating group FE	Yes	Yes
N	2,662,362	195,250
R^2	0.869	0.881

Notes: This table presents the coefficients from the regressions described in Equation (5). Column (1) shows the baseline result using the ratio of value pledged by bank b to total value outstanding of security s as the dependent variable. Column (2) presents robustness using the ratio of value held by banks in country c to total value outstanding of security s as the dependent variable. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B2: Systemic risk and size of issuing bank
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{LargeBank}_{s,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0345***	0.0344***	0.0352***
	(0.00423)	(0.00424)	(0.00425)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.00367	0.00385	0.00353
	(0.00287)	(0.00288)	(0.00287)
$\text{LargeBank}_{s,t-1} \times \text{HaircutGap}_{s,t-1}$	-0.0173***	-0.0171***	-0.0183***
	(0.00231)	(0.00233)	(0.00236)
$\text{HaircutGap}_{s,t-1}$	0.00780***	0.00688***	0.00635***
	(0.00155)	(0.00154)	(0.00155)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	2,130,742	2,130,742	2,130,742
R^2	0.867	0.867	0.867

Notes: This table presents the coefficients from the regressions related to security pledging, as described in Equation (7). Large Bank takes the value of 1 if the issuing bank's size (total assets) is in the top 10% of all banks in the respective country, and 0 otherwise. Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B3: Systemic risk and equity ratio of issuing bank
Full sample of bank bonds

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_{s}}$		
	(1)	(2)	(3)
$\text{LowEquityRatio}_{s,t-1} \times \text{Domestic}_{b,s} \times \text{HaircutGap}_{s,t-1}$	0.0206***	0.0195***	0.0203***
	(0.00200)	(0.00199)	(0.00205)
$\text{HighEquityRatio}_{s,t-1} \times \text{Domestic}_{b,s} \times \text{HaircutGap}_{s,t-1}$	0.0149***	0.0134***	0.0140***
	(0.00286)	(0.00287)	(0.00290)
$\text{LowEquityRatio}_{s,t-1} \times \text{Foreign}_{b,s} \times \text{HaircutGap}_{s,t-1}$	-0.0107***	-0.0119***	-0.0112***
	(0.00231)	(0.00232)	(0.00231)
$\text{HighEquityRatio}_{s,t-1} \times \text{Foreign}_{b,s} \times \text{HaircutGap}_{s,t-1}$	-0.00220	-0.00368	-0.00312
	(0.00270)	(0.00271)	(0.00278)
Controls	No	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	No	No	Yes
N	1,226,806	1,226,806	1,226,806
R^2	0.884	0.884	0.884

Notes: This table presents the coefficients from the regressions related to security pledging, as described in Equation (7). We denote a security as being issued by a LowEquityRatio bank if the issuing bank belongs to the 10% of least capitalized banks in the respective country, and HighEquityRatio bank otherwise. Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B4: Binding vs. non-binding downgrades
Restricted sample of bank bonds: ECB institutional rules

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$	
	(1)	(2)
$\text{Treated}_i \times \text{Post}_t$	0.000634**	-0.000600
	(0.000286)	(0.000740)
$\text{Treated}_i \times \text{Post}_t \times \text{Domestic}_{s,b}$		0.00259***
		(0.000962)
Controls	Yes	Yes
Time FE	Yes	Yes
Bank FE	Yes	Yes
ISIN FE	Yes	Yes
N	42,130	42,130
R^2	0.925	0.925

Notes: This table presents robustness to the Identification strategy using ECB institutional rules: Binding vs. non-binding Downgrades. Using the sample of securities rated at A-, we isolate the effect on pledging around a one notch downgrade (in the window of +/- 2 months around the downgrade from A- to BBB+). As the ECB considers only the best rating across the four agencies, we distinguish between two types of downgrades: Treated (non-binding downgrades, that do not affect the first best rating, i.e. ECB does not change the haircuts) and Control (binding downgrades, where both the ECB and private markets adjust the haircuts). The following equation summarizes the setup:

$$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = \alpha_b + \alpha_s + \alpha_t + \beta(\text{Treated}_s \times \text{Post}_t) + \gamma X_{s,t-1} + \epsilon_{s,b,t}$$

Standard errors are clustered at the security and time level. *** p<0.01, ** p<0.05, * p<0.1.

C Raw sample

Table C1: Systemic risk: bank similarity (Robustness: raw data)

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
HaircutGap$_{s,t-1}$ × Domestic$_{s,b}$	0.0260***		
	(0.00602)		
HaircutGap$_{s,t-1}$ × Foreign$_{s,b}$	-0.0167***		
	(0.00386)		
Periphery$_b$ × Domestic$_{s,b}$ × HaircutGap$_{s,t-1}$		0.0210***	
		(0.00561)	
Periphery$_b$ × Foreign$_{s,b}$ × HaircutGap$_{s,t-1}$		0.0047	
		(0.0111)	
Core$_b$ × Domestic$_{s,b}$ × HaircutGap$_{s,t-1}$		-0.0236	
		(0.0210)	
Core$_b$ × Foreign$_{s,b}$ × HaircutGap$_{s,t-1}$		-0.0220***	
		(0.00344)	
HaircutGap$_{s,t-1}$ × Correlation$_{s,b,t-1}$			0.0382***
			(0.00990)
HaircutGap$_{s,t-1}$			-0.000448
			(0.00579)
Controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
ISIN FE	Yes	Yes	Yes
Rating group FE	Yes	Yes	Yes
N	150,567	150,567	55,640
R^2	0.898	0.898	0.944

Notes: This table uses the raw data only as a robustness. A security is denoted as Domestic if the pledging and issuing banks have the same country of location, and as Foreign otherwise. Furthermore, we divide the pledging banks into two categories: Periphery and Core based on their location. Periphery denotes Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while Core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands. Correlation denotes the correlation coefficient between the bond prices of pledging and issuing bank. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table C2: Systemic risk: bailout expectations (Robustness: raw data)

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$	
	(1)	(2)
$\text{Domestic}_{s,b} \times \text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}$	0.0380***	
	(0.0121)	
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0240***	0.0141**
	(0.00622)	(0.00621)
$\text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}$	-0.0186**	
	(0.00759)	
$\text{HaircutGap}_{s,t-1}$	-0.00552	-0.0120***
	(0.00474)	(0.00357)
$\text{CrossPledge}_{s,b,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$		0.0765***
		(0.0136)
$\text{CrossPledge}_{s,b,t-1} \times \text{HaircutGap}_{s,t-1}$		-0.00683
		(0.00494)
Controls	Yes	Yes
Time FE	Yes	Yes
Bank FE	Yes	Yes
ISIN FE	Yes	Yes
Rating group FE	Yes	Yes
N	137,151	141,519
R^2	0.911	0.908

Notes: This table uses the raw data only as a robustness. SRISK takes the value of 1 if the issuing bank's SRISK ratio is in the top 10% of SRISK ratios of all banks in the respective country, and 0 otherwise. Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. The categorical variable CrossPledge takes the value of 1 if the bank that issues the security s has pledged bonds issued by bank b at time $t-1$, and 0 otherwise. Domestic takes the value of 1 if the pledging and issuing banks have the same country of location, and 0 otherwise. Controls include log values of security residual maturity and price. Standard errors are clustered at the security and time level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.