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

Martina Jasova[‡] Luc Laeven[§] Caterina Mendicino[¶]
José-Luis Peydró[‖] Dominik Supera[**]

Abstract

We show that lender of last resort (LOLR) policy contributes to higher interconnectedness and the buildup of 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 by private repo markets. We exploit the variation across securities in the *haircut gap*, i.e. the difference in valuation haircuts between the private market and the central bank. We find that LOLR policy provides incentives for banks to increase their holdings of bonds with higher haircut gaps, especially those issued by other, interconnected, banks. This is consistent with theories of *interbank monitoring* rather than *risk sharing*. Stronger interconnectedness arises from an increase in *home bias*, especially for banks in distressed economies. Among domestic banks, higher haircut gaps increase the pledging of bonds issued by systemically important banks and stimulate the cross-pledging of bank bonds, in line with theories of *bailout expectations* in the event of a systemic crisis. Consistent with an increase in the demand for bank bonds with higher haircut gaps, we also document that LOLR policy stimulates their issuance by banks in distressed economies.

JEL classification: E44, E52, E58, F30, G01, G21.

Keywords: Central Bank Liquidity, Haircuts, Collateral, Bank Risk Concentration, Systemic Risk.

[*]We thank Itay Goldstein, Arvind Krishnamurthy, Philipp Schnabl and Annette Vissing-Jorgensen for helpful comments and suggestions. We are grateful to Felix Corell, Dominika Ehrenbergerova, and Federico Seibold for superb research assistance. The opinions expressed herein are those of the authors and do not necessarily reflect those of the ECB or the Eurosystem.

[‡]Barnard College, Columbia University. Email: mjasova@barnard.edu

[§]European Central Bank, DG-Research, and CEPR. Email: luc.laeven@ecb.europa.eu

[¶]European Central Bank, DG-Research, Monetary Policy Research. Email: caterina.mendicino1@ecb.int

[‖]Imperial College London, ICREA-Universitat Pompeu Fabra CREI Barcelona GSE, and CEPR. Email: jose.peydro@gmail.com

[**]Wharton School, University of Pennsylvania. Email: superad@wharton.upenn.edu

Introduction

In response to severe liquidity squeezes and market malfunctions during the Global Financial Crisis, central banks expanded their liquidity provision to an unprecedented scale and scope to ensure the proper functioning of the banking sector and the transmission of monetary policy. These large-scale operations by the central bank renewed the debate on the constraints and boundaries of lender of last resort (LOLR) policies, including on the appropriateness of central banks' liquidity and collateral frameworks (e.g. Calomiris et al., 2016). One particular concern is that collateral policies may have been too generous, creating moral hazard in central bank lending operations and exposing the central bank to undue credit risk (Drechsler et al., 2016; Nyborg, 2016; Bindseil et al., 2017). Still, after more than a decade of experience with large scale liquidity operations, little is known about whether and how these policies affect systemic risk.

In this paper, we show that LOLR policy affects bank interconnectedness and contributes to the buildup of systemic risk in the banking sector. Our analysis focuses on the provision of liquidity to banks by the European Central Bank (ECB) during the financial and sovereign debt crisis, when the LOLR played a key role in supporting banks. We examine the haircut gap channel of the LOLR – i.e. the difference in valuation haircuts between the private market and the central bank for securities that can be pledged as collateral in LOLR operations.

The ECB experience offers an ideal setting to study the implications of LOLR policy because the Eurozone has been hit by multiple crises – e.g. the Global Financial Crisis and the European Sovereign Debt Crisis – and the ECB provided full allotment of funds in the form of repurchase agreements (repo) against adequate eligible collateral. Figure 1 shows that total bank borrowing from the ECB more than doubled during the Global Financial Crisis and reached unprecedented levels (a peak of EUR 1.2 trillion) in the middle of the European Sovereign Debt Crisis. Moreover, banks pledged a substantially larger share of bank bonds than sovereign bonds to obtain ECB liquidity (Figure 2).

We build a unique linked dataset that provides a detailed picture of the ECB and private repo markets. First, we exploit a set of micro-level proprietary datasets that allow us to observe detailed information on the banks' security pledging with the ECB in LOLR operations. The data covers individual security (ISIN) level information on more than 20,000 bank- and government-issued securities pledged as collateral by all reporting counterparties to obtain LOLR funding. In addition to the amount of liquidity obtained by each individual bank in any given date, we observe rich information on the corresponding collateral pledged, e.g. issuer, haircut, rating, residual maturity, security type, amount pledged and outstanding. Second, we link the confidential ECB data with private market haircut data 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] To the best of our knowledge, we are the first to fully exploit the combination of these rich data sources.

The richness of our dataset allows us to assess the importance of the haircut gap at the most granular level and with extraordinary breadth and coverage. We use the linked granular data to construct security-level time-varying haircut gaps. A high haircut gap associated with a security pledged as collateral with the LOLR means that the ECB applies a much more favorable valuation of that asset compared to the private repo market. Hence, this increases the borrowing capacity of banks against the collateral pledged with the ECB. The highest haircut gaps are observed on bonds issued in periphery countries in the height of the Sovereign Debt Crisis.

Our main hypothesis is that LOLR funding provides incentives for banks to pledge bonds issued by other banks featuring high haircut gaps, thus contributing to the buildup of systemic risk. Before exploring the systemic risk implications of LOLR, we first analyze the impact of LOLR collateral policies on the banks' collateral pledging behavior.[2] We document that over our sample period bank-issued bonds represent an important share of collateral asset type used in liquidity operations (Figure 2). Interestingly, over time banks located in periphery countries remarkably increased their pledging of bonds issued by other domestic banks. This pattern is consistent with the evolution of their holdings and issuances (Figure 3).[3]

As bank bonds are primarily held by other banks (Figure 4), it follows that bank-issued bonds are quite sensitive to changes in the private versus central bank valuation of the collateral for LOLR liquidity, which is only accessible to banks. We show that banks increase

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

[2]While our analysis focuses on the collateral pledging by banks with the ECB, the changes in pledging behavior reflect actual changes in the holdings of securities and not merely the pledging of previously held collateral. Using a matched security holding and pledging data for a subset of banks, 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 A1.

[3]We exclude from the analysis own issued bonds, as well as bonds issued by other banks in the same banking group.

the pledging of securities featuring higher haircut gaps, and in particular of those issued by other banks, giving rise to a haircut gap channel of LOLR funding. 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 bonds compared to the mean value of pledged securities as a share of the value outstanding at the individual bank level.

The main contribution of this paper is to provide evidence of the systemic risk implications of LOLR funding, through the haircut gap channel. While the implications of LOLR policy for the sovereign-bank nexus are well understood (e.g. Acharya and Steffen, 2015; Drechsler et al., 2016), the impact of LOLR on the interconnectedness and concentration of bank risks has so far been unexplored. Financial interlinkages among banks is important as these are at the core of systemic risk (Allen and Gale, 2000; Freixas et al., 2000; Acemoglu et al., 2015; Cabrales et al., 2017).

We show that changes in the haircut gap have significant effects on the financial system with important implications for systemic risk. We exploit the variation in the haircut gap across securities and find that LOLR policy provides incentives for banks to pledge bonds featuring higher haircut gaps issued by other highly interconnected banks, in line with theories of interbank monitoring (e.g. Rochet and Tirole, 1996). Stronger interconnectedness arises from the increase in the pledging of domestic bank-issued bonds, especially in distressed peripheral countries of Europe. 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 bonds issued by systemically important banks, consistent with theories of bailout expectations in the event of a systemic crisis (e.g., Acharya and Yorulmazer, 2007; 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 adopt SRISK (Brownlees and Engle, 2017) as a measure of systemic risk. Our results are also robust to the use of other measures, such as size.

Moreover, we also find that a higher haircut gap is associated with an increase in the cross-pledging of bank bonds within domestic banks, further amplifying the "too-many-to-fail" problem (e.g., Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012). With cross-pledging, we refer to the situation in which bank A pledges more bank B bonds and bank B pledges more bank A bonds. Following Elliott et al. (2014), our evidence lends support to integration motives (deeper relationships with each counterparty) as opposed to diversification motives (more counterparties). 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. In their setup, banks are indirectly interconnected through the asset markets and when bank assets are homogeneous, the feedback loop between bank runs and fire sales is exacerbated. Our paper documents an additional layer of (direct) interconnectedness triggered by the cross-holding of bank bonds incentivized by LOLR policy. Higher haircut gaps increase the direct linkages across banks and, hence, weaken the stability of the whole banking sector.

Next, we consider two dentification strategies that exploit specific institutional features of the ECB haircut policy. In the first identification strategy, we exploit the nonlinearities in the haircut gap with respect to the rating. This identification relies on the fact that the ECB only applies two levels of haircuts: a lower haircut level for AAA to A- ratings and a higher one for BBB+ to BBB- ratings. Hence, for a given security type, the ECB haircut profile displays only one jump, i.e., from A- to BBB+. On the contrary, the market haircuts react to every notch downgrade, with larger increases in haircuts for downgrades at the bottom tier of the investment grade rating. As a result, a one notch downgrade in ratings affect the haircut gap differently depending on the ex-ante rating level. This allows us to empirically test the hypothesis that following a one notch downgrade, the pledging with the ECB increases by more at notches that trigger a larger jump in the haircut gap.[4]

The second identification strategy exploits the fact that, contrary to the private markets, the ECB considers only the best rating across the 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. On the contrary, if the downgrade does not affect the first best, only the private market valuation haircut will be increased. The latter implies a larger haircut gap than the former. We test the hypothesis that downgrades at A- that do not affect the first best rating provide incentives for banks to pledge more of the downgraded assets with the ECB.

Finally, consistent with the increased demand for bank bonds with higher haircut gaps in LOLR operations, we also find that higher haircut gaps are associated with subsequent higher issuance of bonds by banks, hence, increasing their overall dependence on bond market

[4]A downgrade from A to A- should, for instance, have a larger effect compared to a downgrade from A+ to A.

financing. This effect is particularly strong for banks in distressed periphery economies.

Our results are quantitatively important, not least because European banks tend to hold a large fraction of bank bonds in their balance sheets and use banks bonds disproportionately in liquidity operations. Figure 4 shows that while government debt is widely held across a range of sectors, bank bond holdings are concentrated within the banking sector. This is consistent with banking being a particularly opaque industry (e.g. Morgan, 2002). In addition, from the perspective of the banks' own security portfolio, bank-issued securities are at least as important as sovereign debt. Bank bonds constitute approximately one third of all securities held by banks. Hence, in the euro area banks' funding structures are highly intertwined, with large cross-holdings of debt securities issued by other banks (see also Bekaert and Breckenfelder, 2019).

Our work contributes to the literature on LOLR policies. A growing number of papers provides theoretical arguments regarding the beneficial effects of LOLR policy (e.g., Bagehot, 1873; Diamond and Dybvig, 1983; Rochet and Vives, 2004; Freixas et al., 2010; Stein, 2012), with empirical evidence showing the positive effects on lending (e.g., Cahn et al., 2018; Jasova et al., 2021; van Bekkum et al., 2018) and on financial markets (e.g., Pelizzon et al., 2020). An exception is Drechsler et al. (2017) who show that ECB liquidity operations increased the pledging of distressed-sovereign bonds (risky collateral) by weakly capitalized banks and their corresponding holdings in the aftermath of the first Greek bailout (June 2010 to December 2011). We complement previous findings by presenting credible evidence on the effects of LOLR policy on interconnectedness and the buildup of systemic risk in the banking sector. Consequently, compared to Drechsler et al. (2017) who focus on government debt, our focus is on the pledging of bank bonds.

Our work 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., Rochet and Tirole, 1996; Allen and Gale, 2000; Freixas et al., 2000; Elliott et al., 2014; Acemoglu et al., 2015; Cabrales et al., 2017; Abbassi et al., 2021), we explore systemic risk that arises from the cross-holding of bank-issued securities. Such cross-holdings of bank bonds are large (see also Bekaert and Breckenfelder, 2019) and dominate the securities pledged as a collateral with the central bank.[5] In particular, we show that through higher haircut gaps, the LOLR stimulates the buildup of systemic risk via banks pledging of bonds issued by other domestic banks, especially in distressed periphery countries. These results cannot be explained by

[5]In the euro area, the cross-holding of bank-issued securities has become more relevant than interbank deposits in recent times (see e.g., ECB, 2015).

risk sharing motives as in Allen and Gale (2000, 2007) or by a broad reach for yield (see e.g., Rajan, 2006; Ivashina and Scharfstein, 2010; Adrian and Shin, 2010). Instead they are consistent with the literature on information and peer monitoring (see e.g., Rochet and Tirole, 1996; Freixas et al., 2000). 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 relates to Goldstein et al. (2020) who show that homogeneity in banks' asset holdings amplifies the fragility of the financial sector.

We also connect to the literature on the sovereign and bank risk nexus (e.g., Acharya et al., 2014; Acharya and Steffen, 2015; Battistini et al., 2014; Becker and Ivashina, 2018; Altavilla et al., 2017) which shows important results on the holding of distressed-sovereign debt by banks. We focus on the concentration of bank risk within the banking sector, and show that this aspect, over-looked by previous literature, also has important implications for LOLR policy in terms of their repercussions for the buildup of systemic risk.

Finally, this paper also links to the literature on the impact of unconventional monetary policy. In particular, 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., Krishnamurthy and Vissing-Jorgensen, 2011; Chodorow-Reich, 2014; Krishnamurthy et al., 2017; Koijen et al., 2021) and bank lending (e.g., Chakraborty et al., 2018; Rodnyansky and Darmouni, 2017; Heider et al., 2019; Di Maggio et al., 2020; Peydro et al., 2021; Jasova 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 methodology. 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 draws implications for the issuance of bank debt. Finally, Section 8 concludes.

1 Institutional Background

This section presents stylized facts regarding the key holders of bank and government securities 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 4 compares the holdings of bank and government securities in the euro area, which are at the core of our analysis. Panels (a)-(b) display the share of bank and government bonds held by different institutional sectors, whereas panel (c) compares their holdings within the banking sector.[6] European banks hold a remarkably large share of bonds issued by (other) banks. Further, banks are the largest holders of bank-issued bonds in the economy, while 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. Battistini et al., 2014; Acharya et al., 2014; Acharya and Steffen, 2015; Becker and Ivashina, 2018; Drechsler et al., 2016; Altavilla et al., 2017) we complement previous findings by documenting that euro rea 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.[7] 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).[8] In line with the Bagehot principle, the ECB provide unlimited allotment of funds to European banks against adequate collateral, at a "penalty" interest rate.[9]

[6] Figure 4 refers to Q1 2014. Importantly, the results are broadly unchanged over the whole sample period.

[7] This paper focuses on the LOLR funding built into the monetary policy operational framework, which provides the bulk of liquidity to the banking system and features a number of counterparties remarkably larger than other major central banks (For details on the Eurosystem collateral framework, see Bindseil et al., 2017). 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.

[8] 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 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.

[9] The ECB charges an interest rate on the main refinancing operations (MRO) higher the the one charged on private repo funds (http://www.repofundsrate.com/). This represents "a 'penalty' for borrowing from the LOLR and imposed a cost on banks for taking up haircut subsidies" (see Drechsler et al., 2016).

Figure 1 summarizes the development of ECB liquidity received by all banks in the euro area. The 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 adequate collateral across a large number of banks and countries, the ECB provides liquidity against a wide range of eligible collateral. 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).[10]

Pledged Collateral. What do banks pledge with the LOLR as a collateral? By analyzing the composition of pledged securities with the ECB across all euro area banks over time, we observe that the dynamics in pledging of bank bonds has shaped the overall pledging of banks in the Eurozone. Figure 2 (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 2 (Panel (b)) zooms in 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). Domestic bank-issued bonds where disproportionately more used as a collateral by banks located in core countries in the aftermath of the Global Financial Crisis. On the contrary, banks located in distressed periphery countries increased remarkably their pledging of bonds issued by other domestic banks only since the start of the European Sovereign Debt Crisis. The evolution of the pledging of bank-issued bonds displayed in Figure 2 (Panel (b)) is consistent with the evolution of the holdings of domestic and foreign bank bonds reported in Figure 3 (Panel (a)).

While our analysis focuses on the security pledging by banks, the changes in pledging behavior reflect actual changes in the holdings of securities and not merely the pledging of previously held collateral. Previous work documented that security holding and pledging of banks are very similar and banks predominately pledge these securities with the ECB (see

[10] To make the credit ratings comparable across systems and sources, the grades are mapped to a harmonized rating scale of 5 steps. For detailed information on the Eurosystem's harmonized rating scale: https://www.ecb.europa.eu/paym/coll/risk/ecaf/html/index.en.html

Jasova et al., 2021). Appendix Figure A1 documents banks' pledging vs holding behavior and it shows that on average banks pledge over 90% of securities held (see Panel b).[11] In addition, the timing of pledging of newly issued securities suggests that banks pledge over 75% of newly acquired securities within 3 months from the security issuance date.

Haircuts. The amount of liquidity a bank can obtain from the ECB against the collateral crucially depends on the applied haircut.[12] The ECB haircut valuation is primarily determined by a combination of issuer group (government, bank, corporate, etc.), asset type (covered bonds, uncovered bonds, etc.), rating and residual maturity.[13] The basic valuation matrix as well as any temporary or permanent changes to this valuation framework are publicly communicated and available from 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 2008, the haircuts applied by the ECB were similar to the private market haircuts on repo loans (see also Drechsler et al., 2016). However, afterwards, the ECB started offering haircuts significantly below that of the private repo markets. In detail, over the 2009–2015 period, the ECB applied average haircut of 4.9% while private market averages to 15% haircuts. See Table 1 (top panel). In this paper, we argue that this divergence in valuations represents a crucial aspect of the LOLR provision of liquidity, with important consequences for systemic risk in the banking sector.

2 Data

We construct a unique micro-level dataset that matches comprehensive proprietary ECB data on the main refinancing operations (liquidity and collateral) with private repo market

[11] Data on individual banks' security holdings are only available for a subset of banks used in our analysis over the 2014:Q1-2018:Q4 period.

[12] Data about the aggregated collateral amount used by counterparties is available on the website on a quarterly bases.

[13] See https://www.ecb.europa.eu/paym/coll/risk/liquidity/html/index.en.html for detailed information about ECB haircut categories.

[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. This paper focuses on marketable securities widely accepted also by the private repo market. Nevertheless, the share of the non-marketable securities is not sizable (less than 5% of all pledged assets).

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

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 2009m1–2015m3 period capturing both the Global Financial Crisis and 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. In this section we describe the various data sources, before turning to the empirical framework.

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 central bank liquidity. This is the largest cross-country liquidity and collateral dataset, covering over 19 countries and 2,000 counterparties.[17] In addition to the amount of liquidity obtained by each individual bank in any given date, the dataset provides detailed information for 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,...), security type (bond, note, covered bond, ABS...), issuance and maturity date, security guarantor. It also provides information on 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). The information is available at the level of each individual security (ISIN-level). This is crucial for our analysis, as it allows us to assess the importance of LOLR policy at the most granular level and with extraordinary breadth and coverage.

Private haircuts. We create a novel dataset that provides a detailed picture of the ECB and private repo markets in Europe. To this end, we use the private repo market data from the two leading exchange and clearing houses in Europe: LCH Clearnet and EUREX. We observe monthly series of private market haircuts for securities of different type, rating and maturity. In addition, we also impute the private repo market data from the clearing houses through a random forest machine learning prediction algorithm for the universe of bank- and government-issued securities used in monetary policy operations with the ECB.[18]

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

[17] The ECB counterparties are all euro area credit institutions (unconsolidated level) supervised according to harmonized EU standards.

[18] For details about the random forest, see Appendix A.1. Alternatively, we also repeat the prediction

Securities and issuer ratings. The Eurosystem Centralized Securities Database (CSDB) consolidates security-by-security data (instruments, issuers and prices) from both internal and commercial sources. It provides ratings on the credit quality of marketable securities according to the Eurosystem 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 confidential bank balance sheet 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 banks operating in the euro area. We use this data to construct time-varying bank level controls such as size, ratio of security holdings to total assets, equity ratios etc. Furthermore, we use the data on bank ownership structure from Bankscope and Register of Institutions and Affiliates Database (RIAD) to construct the group structure of banks. This information allows us to identify the pledging of own bank bonds or bank bonds issued by banks within the same group. Finally, we use information on banks' bond and equity prices, and leverage from Datastream to construct the SRISK measure (see Brownlees and Engle, 2017).

Security holding data. Information on security-by-security holdings of debt securities (SHS) by institutional sectors in the euro area is available on a quarterly basis by the European System of Central Banks. The SHS data report holdings for 22 institutional sectors. We group them into banks, other financial institutions (OFIs) insurance companies and pension funds (ICPFs), Households (HH), central government (Gov), non-financial corporations (NFCs) and others. The high granularity of the data (ISIN-level) allows us to document the main holders of bank and government bonds. In addition, we also use SHS data to compare the evolution of the holding of bank bonds by banks and their pledging behavior over time.

exercise using a Bayesian Model Averaging (BMA) approach and simple linear regressions. The result of all prediction techniques as well as original unimputed sample (from the clearing houses) are reported in the Appendix Table A3.

3 Methodology

3.1 Haircut Gap

According to the Bagehot's dictum "to avert panic, central banks should lend early and freely (i.e. without limit), to solvent firms, against good collateral, and at 'high rates' " (see Tucker, 2009), where by good collateral is intended "everything that in common times is a good banking security" (see Bagehot, 1873). Hence, in the absence of any subsidy, LOLR lending would offer no benefits to banks over the private market (e.g. Drechsler et al., 2017).

How is the LOLR principle reflected in the ECB liquidity policy? This section examines the banks' liquidity-providing repo operations with the ECB using a novel dataset that matches ECB and private market data at the security level over the 2009–2015 period.

One of the main contributions of this paper is to measure the disconnect between ECB and private repo market haircuts for a large sample of securities pledged by banks across the Eurozone. To this end, we link the detailed collateral data of the ECB with the private repo market haircuts. We measure the haircut gap as the difference between the private market and ECB valuation of a pledged security type s at time t:

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

where the security type s is defined over the following characteristics: issuer group, issuer rating and residual maturity basket. Table 1 (top panel) provides the detailed 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 averages to 12% haircuts.

Figure 5 illustrates the diverting trajectory of haircut gap by securities issued in core and peripheral countries.[19] Since the downgrade of Greece's credit rating in April 2010, the Eurozone experienced a wave of rating downgrades of securities in periphery countries. Rating downgrades substantially increased private market haircuts and thus limited the borrowing capacity of banks from private repo market against this risky collateral. Furthermore, in some cases banks became completely cut off from the wholesale funding markets and further increased their dependence on the LOLR funding (see e.g., Alves et al., 2016). In contrast, the ECB did not increase the haircuts on risky securities to the extent observed in the private

[19] We define periphery countries as Italy, Spain, Portugal, Ireland, Cyprus, Malta and Greece while core denotes Austria, Belgium, France, Germany, Luxembourg and the Netherlands.

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 which drove up the haircut gap for securities issued in the region. In Figure 5, we illustrate a significant increase in the haircut gap for securities issued in periphery countries, while the gap for securities issued in the core countries continued to oscillate around 0. Finally, we document that this overall divergence is robust to using book or market valuations as weights and it holds for periphery countries at large even if we exclude the unique case of Greek bonds.[20]

3.2 Empirical Strategy

We exploit the variation in the haircut gap at the cross-section of securities (ISIN-level) over time. We first document key effects of changes in the haircut gap on the pledging behavior of banks in the euro area. Second, we consider two more targeted identification strategies that exploit ECB haircuts rules. In our empirical analysis, we test the hypothesis that banks increase pledging of securities characterized by higher haircut gaps. Our granular data will allow us to investigate which type of securities benefit the most from higher haircut gaps.

3.3 Full Sample

In the first part of the analysis we examine the impact of changes in haircut gap over time across a large number of securities. Hence, we do not focus on any specific LOLR intervention. Specifically, we use the difference in the haircuts of the private market and the ECB while controlling for security riskiness, and observable and unobservable security characteristics. 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:

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

[20]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.

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.[21] In Section, 4, we consider marketable securities which are issued by both the central government or banks in EA countries. In the main part of the paper, which focuses on systemic risk, we only consider bank-issued securities.

$\text{HaircutGap}_{s,t-1}$ refers to the difference in haircut valuation of security s by private repo markets and the central bank (as explained in equation 1). In addition to the average effect of haircut gap on the bank pledging behavior, we also focus on the heterogeneity in the 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 aspects of LOLR policy.

Importantly, we saturate the specification with 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 variation. 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, existence of guarantees etc.). In addition, we progressively introduce time-varying controls (security price and remaining maturity) captured by $X_{s,t-1}$. Finally, we introduce rating group FE (α_r).[22]

3.4 Two Identification Strategies

In the second part of the analysis we exploit two specific institutional features of the ECB haircut policy that are not used by the private repo markets: (i) the two-step haircut profile and (ii) the first best rating rule.

Identification: kinks and jumps. In this first identification strategy, we exploit the nonlinearities in the haircut gap sensitivity with respect to the rating. For each type of security[23] the ECB applies only two discrete choices of haircut: a lower haircut value if the

[21] As a robustness check, we also perform the same analysis using an alternative measure of pledging expressed as log value of pledged asset.

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

[23] By type we refer to a security of a given asset class, institutional type of issuer, residual maturity, structure of coupon payments

rating is equal or better than A- and a higher haircut if the rating ranges between BBB+ and BBB-.[24] Hence, while private markets adjust their haircut valuation at every notch downgrade, the ECB haircuts only react from A- to 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 best rating and haircut levels for a common class of pledged assets - unsecured bond issued by credit institution with 1-3 year residual maturity and fixed coupon payments. Panel A depicts haircut levels (in percent) set by the ECB and 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+. 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. We see that the derivative of the haircut gap with respect to the rating change is not constant. 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 by 6 percentage points.

We restrict the sample to events of one-notch rating changes and exploit the effect of these non-linear kinks and jumps in the haircut gap 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 notches which trigger a larger jump in the haircut gap.

Identification: 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 takes into account only the best rating of the four rating agencies (S&P, Moody's, Fitch and DBRS).

In this empirical strategy, we focus on securities with best rating at A- cliff that suddenly experience a one notch downgrade. From the perspective of the central bank, this one notch

[24] The ECB uses three rating steps. It applies the same level of haircut to Step 1 and Step 2 (AAA to A-) and a higher one to Step 3 (BBB+ to BBB-). For details, see https://www.ecb.europa.eu/press/pr/date/2010/html/sp090728˙1annex.en.pdf

downgrade can affect the first best rating (it will be *binding*) or not (non-binding downgrade). If the downgrade is binding, the first best rating is affected and both the ECB and the private markets will move to higher (BBB+) haircut valuations. If the rating downgrade does not impact the first best rating, only the private market will increase the valuation haircuts. As a result, downgrades at A- that do not affect the first best rating will be associated with a higher haircut gap than binding ones. We test the hypothesis that downgrades that do not trigger a haircut change by the central bank provide greater incentives for banks to pledge more of the downgraded assets in LOLR liquidity-providing repo operations.

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 4, 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 systemic risk.

Specifically, we examine the hypothesis that LOLR contributed to increased pledging of bonds issued by other banks to obtain central bank funding. In particular, we explore the heterogeneous impact of the haircut gap on the ratio of pledged securities to total value outstanding and examine the differential effects for bank bonds. Equation 3 summarizes the set-up:

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

Table 2 summarizes the results. Column (1) shows that banks increase their pledging of securities which feature higher haircut gaps.[25] 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 in response to higher haircut gaps, bank bonds benefit more than government bonds from the same increase in pledging. 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 bank (government) as a share of the value outstanding. As shown in Figure 4, the holding of bank bonds is heavily concentrated in the balance sheet of banking institutions who have 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. Hence, 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 opposed to government bonds. In Section (Section 5) we will 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

In this section and throughout the rest of the paper, we focus exclusively on the bank bonds, which are at the core of our analysis. We zoom into what type of bank-issued securities benefited the most from a favorable haircut gap. This examination allows us to test whether higher haircut gaps exacerbate 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

[25]To avoid a bias in our estimates, our sample restricts only to bank bonds issued by banks that do not belong to the same banking group as the pledging institution.

systemically risky banks (SRISK), or featuring strong interlinkages with them. Importantly, in order not to confound our results with other factors, 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 through the haircut gap the LOLR provided incentives to banks to increase their pledging of bonds issued by banks similar to them. We proxy for bank similarity in two ways. First, we consider their location and examine differences in pledging responses across securities issued by banks located in the same country or abroad. Second, we use the correlation between bond prices of the pledging and the issuing bank.

Domestic vs foreign bank bonds. First, we split the securities issued by banks in two categories: domestic and foreign. Equation 4 summarizes the set-up:

$$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1(\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}) + \\ + \beta_2(\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,b}) + \beta_3 \text{Domestic}_{s,b} + \gamma X_{s,t-1} + \epsilon_{s,b,t} \quad (4)$$

A security is denoted as domestic if the pledging and issuing banks have the same country of location, and as a foreign otherwise. Table 3 presents the results. All specifications highlight that the increased pledging of bank-issued bonds associated with higher haircuts is completely attributable to the pledging of bonds issued by domestic banks. In fact, foreign bank bonds deliver non-significant estimates. Our findings suggest that the LOLR contributed to an increase in the home bias through 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 bank level.

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 of 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 (see Morgan, 2002) and hence with more substantial monitoring needs.

Domestic bank bonds in core vs periphery. In light of the findings above some questions naturally emerge: 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 (see Figure 5), we split the pledging banks into two categories: $Periphery_b$ and $Core_b$. We combine these two margins to create four distinctive categories. Equation 5 summarizes the set-up:

$$\begin{aligned}\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = {} & \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1(\text{Periphery}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) \\ & + \beta_2(\text{Periphery}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}) \\ & + \beta_3(\text{Core}_b \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) \\ & + \beta_4(\text{Core}_b \times \text{Foreign}_{s,b} \times \text{HaircutGap}_{s,t-1}) \\ & + \gamma_1(\text{Periphery}_b \times \text{Domestic}_{s,b}) + \gamma_2(\text{Periphery}_b \times \text{Foreign}_{s,b}) \\ & + \gamma_3(\text{Core}_b \times \text{Domestic}_{s,b}) + \delta X_{s,t-1} + \epsilon_{s,b,t}\end{aligned} \tag{5}$$

The results in Table 4 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. In addition, it further corroborates the home bias documented earlier. By providing a favorable haircut gap, the LOLR incentivized the concentration of bank risk within the domestic banking sector, especially in periphery countries. Our findings provide valuable insights to explain the disproportional holding of bank risk by other banks in the Eurozone, with especially high domestic concentration in periphery countries. This result is also consistent with the overall evolution of bank bond holdings by other banks presented in Figure 3. As in our regressions, Figure 3 shows a distinct increase in the holdings of domestic bank bonds by other banks in periphery countries in periods of high haircut gaps. Instead, the holdings of all bank bonds by core banks and foreign bank bonds by periphery banks decreased throughout the sample in line with results in Table 4.

Furthermore, we do not find a strong evidence that banks located in periphery countries increase their pledging of bonds issued by other banks located in foreign countries. This effect on specific types of (bank-issued) assets, suggests that our findings cannot be explained by the diversification or insurance motive as in Allen and Gale (2000) or by the broad reach for yield rational (see e.g., Ivashina and Scharfstein, 2010; Adrian and Shin, 2010). According to the latter, we should expect a higher loading on risky, high-haircut-gap securities across the entire set of high yields assets regardless of the country of issuance and without distinction between types of assets, i.e. bank or government bonds. In contrast, we find evidence of increased pledging only of domestic securities issued by banks in periphery countries.

Correlation of bond prices. The correlation of banks' bond prices represents another measure of similarity across banks. We use this measure and examine the effect on systemic risk according to the following specification:

$$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} = \alpha_b + \alpha_s + \alpha_t + \alpha_r + \beta_1 \text{HaircutGap}_{s,t-1} + \\ + \beta_2(\text{HaircutGap}_{s,t-1} \times \text{Correlation}_{s,b,t-1}) + \gamma \text{Correlation}_{s,b,t-1} + \delta X_{s,t-1} + \epsilon_{s,b,t} \quad (6)$$

The results in Columns (1)–(3) of Table 5 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 proxing for higher bank interconnectedness).

5.2 Systemically Important Banks

So far, we have established that the haircut gap contributed to the emergence of systemic risk within the national banking sectors 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 contribution of banks. In line in (Brownlees and Engle, 2017), we compute the SRISK measure as a function of bank's size, leverage and long run marginal expected shortfall for all available euro area banks.[26] Finally, we 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.[27]

In light of the previously documented importance of the home bias, we investigate the effects on systemically important banks on average but also in interaction with the domestic indicator. Equation 7 summarizes the triple interaction set-up:

$$\begin{aligned}\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} &= \alpha_s + \alpha_b + \alpha_t + \alpha_r + \gamma X_{s,t-1} + \\ &+ \beta_1(\text{SRISK}_{s,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ &+ \beta_2(\text{SRISK}_{s,t-1} \times \text{HaircutGap}_{s,t-1}) + \\ &+ \beta_3(\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ &+ \beta_4\text{HaircutGap}_{s,t-1} + \beta_5(\text{Domestic}_{s,b} \times \text{SRISK}_{s,t-1}) + \\ &+ \beta_6\text{Domestic}_{s,b} + \beta_7\text{SRISK}_{s,t-1} + \epsilon_{s,b,t}\end{aligned} \tag{7}$$

The main outcome variable considers marketable securities which are issued by banks in EA countries. The results, reported in Table 6, confirm that in response to higher haircut gaps banks pledge more securities issued by other domestic banks (β_3). In particular, however, we find a stronger response for securities issued by more systemically risky 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 coefficient (β_2) is negative, indicating that the stronger effect for systemically risky banks is observed only within the domestic banking sector.[28] 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

[26] In the estimation procedure, we use an extended data period from 2000 to 2015. The baseline result used 22 horizon, 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.)

[27] In the robustness, we also consider a 15 and 20 percentile cut-off.

[28] 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 risky banks.

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) as a simple proxy of the banks' systemic importance. We denote banks as systemically important if their balance sheet size is in the top 10% percent of all banks in the respective country.[29] The results are robust to the use of size rather than SRISK. Appendix Table A1 reports the results based on the split of securities into the ones issued by large vs small banks. Consistently with the SRISK measure, we show the strong and statistically significant pledging response of domestic bank securities issued by large banks.

These findings lend support to the systemic bailout theory proposed by Acharya and Yorulmazer (2007) and Farhi and Tirole (2012). Higher haircut gaps on risky bonds issued by systemically important banks located in periphery countries incentivize the herding behavior by banks and exacerbate the "too many to fail" problem.

5.3 Cross-Holding of Bank Bonds

We now 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-holding of bank bonds? If high haircut gaps exacerbated 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. Equation 8 presents our empirical set-up:

$$\begin{aligned}\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s} &= \alpha_b + \alpha_s + \alpha_t + \alpha_r + \gamma X_{s,t-1} \\ &+ \beta_1(\text{ExistRelation}_{s,b,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) \\ &+ \beta_2(\text{ExistRelation}_{s,b,t-1} \times \text{HaircutGap}_{s,t-1}) + \\ &+ \beta_3(\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}) + \\ &+ \beta_4 \text{HaircutGap}_{s,t-1} + \beta_5(\text{Domestic}_{s,b} \times \text{ExistRelation}_{s,b,t-1}) + \\ &+ \beta_6 \text{ExistRelation}_{s,b,t-1} + \beta_7 \text{Domestic}_{s,b} + \epsilon_{s,b,t}\end{aligned} \tag{8}$$

[29] Similarly to SRISK, the results are robust to alternative 15 and 20 percent thresholds.

We define the categorical variable $ExistRelation_{s,b,t-1}$ that takes the value of 1 if the bank that issues the security s has pledged bonds issued by bank b at time $t-1$.[30] In addition, we also define the variable $NoRelation_{s,b,t-1}$ as been equal to 1 if the bank that issued the security s has not pledged the bonds issued by bank b at time $t-1$.

Table 7 reports the results. LOLR through higher haircut gaps stimulate 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 lend further support to the systemic bailout "too many to fail" theory Acharya and Yorulmazer (2007); Farhi and Tirole (2012).

While this analysis focuses on the cross-pledging of bonds, our findings can be generalized to the security cross-holding. This is consistent with previous work documenting that the security holding and pledging of bank bonds are very similar and banks predominately pledge these securities with the ECB (Jasova et al., 2021). In addition, Appendix Figure A1 documents the pledging vs. holding behavior of banks. On average banks pledge over 90% of securities held (see Panel b). The timing of pledging of newly issued securities suggests that banks pledge over 75% of newly acquired securities within 3 months from the date of security issuance (Panel (a)).

Our finding closely relates 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 and, hence, weaken the stability of the whole banking sector.

6 Identification Strategies: Results

In this section, we examine the effect of haircut gaps on systemic risk using two respective identification strategies introduced in Section 6. By exploiting key institutional features of the ECB haircut policy, we can address potential identification challenges that cannot be addresses in the full sample analysis.

A key insight from the full sample analysis is that LOLR policy provides incentives for

[30] For robustness, we define this variable also contemporaneously or using lags different from $t-1$.

banks to pledge bonds with higher haircut gaps issued by other similar banks. Similarity arises from pledging more domestically issued bank bonds, especially in distressed peripheral Europe, and bonds issued by banks with correlated bond prices. We revisit the estimation results from Section 5 by focusing on the two targeted identification strategies: 'kinks and jumps' and 'binding vs non-binding downgrades' explained in Section 6.

Domestic vs foreign bank bonds. Table 8 summarizes the coefficients from the regression related to the security pledging and home bias, as described in equation 4. 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 while the market haircuts seem to react to every notch downgrade, with larger increases in haircuts for downgrades at the bottom tier of the investment grade rating, the ECB haircut profile displays only one jump, i.e., from A- to BBB+. 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 that trigger a larger jump in the haircut gap.

The results in Columns (1)–(3) of Table 8 provide a picture consistent with the full sample analysis. Higher haircut gaps incentivize banks to increase pledging of domestically issued bank bonds and the effect does not attenuate even after introducing fixed effects and controlling for bond price and maturity.

In Columns (4)–(5) of Table 8, we 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+ 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). The estimates reported in Columns (4)-(5) again highlight the essential role of domestic bonds as the main margin of adjustment consistent with the home-bias theory.

Domestic bank bonds in core vs periphery. Within domestic bank, we further differentiate the effect of LOLR policy in core and peripheral Europe. Table 9 shows thatthe results are driven by the pledging of domestically issued bank bonds in the distressed periphery, even across these two identification strategies. 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.

Correlation of bond prices. In Table 10, we proxy for bank similarity with the correlation of bank bond prices between the pledging and issuing bank. Similarly to the previous results, the estimates attribute the increased dependence on ECB funding to the securities issued by similar banks.

Systemically risky banks. Finally, Table 11 reports the heterogeneous effects for bonds issued by different banks.We confirm that within domestically issued securities, the bonds issued by systemically important banks, as measured by SRISK, drive the overall effect.

Taken together, our results provide consistent evidence in support of the literature on information and peer monitoring (see e.g., Rochet and Tirole, 1996; Freixas et al., 2000). High haircut gaps do not provide incentives for banks to pledge any risky securities with favourable ECB valuation. Instead, 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 bank in line with the systemic bailout theories (see e.g. Acharya and Yorulmazer, 2007; Farhi and Tirole, 2012).

7 Bank bonds issuance

So far, we have shown that in response to higher haircut gaps, banks increased their *demand* for bank-issued bonds. In this section we now explore the *supply* side reaction in the bank bond market to LOLR funding. 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 the security level analysis where we focus on the events on new bank bond issuances. The following question summarized the set-up:

$$\log(\text{value issued})_{s(t)} = \alpha_t + \alpha_r + \alpha_c + \beta \text{HaircutGap}_{s(t-1)} + \gamma X_{s(t)} + \epsilon_{s(t)} \tag{9}$$

$\log(\text{value issued})_{s(t)}$ 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 are not observable. We address this issue by constructing a synthetic haircut gap for time $t-1$ using the actual haircuts of observationally-equivalent securities in time $t-1$. We construct synthetic haircuts using information on asset type, issuer rating, maturity, coupon structure. The underlying identification assumption is that banks use the information on haircut gaps of existing outstanding securities when deciding on the issuance of new debt. Finally, 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 on the bank-time level. We construct the outcome variable as a log value of total issued debt outstanding of bank b at time t. This strategy allows us to distinguish new bond issuances that simply replace maturing debt from issuances that increase bank's aggregate borrowing from the bond market. We estimate the effect of haircut gap on bank-level amount of bond debt outstanding using the following specification:

$$\log(\text{value outstanding})_{b,t} = \alpha_t + \alpha_r + \alpha_b + \beta \text{HaircutGap}_{b,t-1} + \epsilon_{b,t} \tag{10}$$

$\text{HaircutGap}_{b,t-1}$ is a bank-level haircut gap constructed as average security level haircut gap weighted by the value outstanding. We control for issuing bank and issuer rating fixed affects.

Table 12 summarizes both issuance analyses. In both cases, the results reveal higher supply of bank bonds in reaction to higher haircut gap. 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 FE (α_t) and we progressively saturate the model with additional fixed effects. As shown in Columns (2)–(4), the coefficient becomes stronger when controlling for the rating and country of issuer fixed effects. As show in Column (4), a 1 percentage point increase in the haircut gap is associated with the 2.4% increase in the value of bond issuances.

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 replacement of maturating debt. High haircut gaps incentivize banks to issue additional bank bonds and increase the total dependence on the bond market financing.

Figure 3 (Panel (b)) further corroborates the evolution of new bank bond issuances over time. In line with the empirical estimates, we observe high instances of the bank bond issuances in times of high haircut gap, especially in case of peripheral banks, where the haircut gaps were the largest.

8 Conclusion

This paper provides novel evidence on the systemic risk implications of LOLR. Our analysis focuses on the Eurozone which was severely exposed to the Global Financial Crisis and the European Sovereign Debt Crisis and thus, is particularly appropriate to assess the effectiveness of LOLR funding. We build a unique dataset which includes granular information on securities pledged by European banks as a collateral to obtain LOLR funding.

Our analysis exploits the variation in the haircut gap across securities and over time and shows that LOLR policies provide incentives for banks to pledge bonds issued by other interconnected banks, increasing the concentration of bank risk within the banking sector. Our findings highlight an increase in home bias in the pledging of bank-issued bonds, especially in distressed periphery countries. By exploiting the variation within domestic banks we also find that higher haircut gaps increased the pledging of bonds issued by systemically important banks, in line with systemic bailout theory. Importantly, LOLR policies stimulated the direct cross-pledging of bank bonds further amplified systemic risk. Finally, due to an increased demand for banks bonds, LOLR also positively affected the prices of these securities and their issuance. Taken together, we uncover a new haircut channel of monetary operations, which encouraged an increase in the concentration of bank risk withing the banking sector. This potentially adverse effect of LOLR policies should ultimately be evaluated against other effects identified in the literature, including the beneficial effects of LOLR operations in terms of supporting bank credit to the private sector.

References

Abbassi, Puriya, Falk Brauning, Peydro, Falko Fecht Fecht, and Peydro Jose-Luis, 2021, International financial integration, crises and monetary policy: Cross-border interbank lending during the euro crises, *Journal of International Economics* forthcoming.

Acemoglu, Daron, Asuman Ozdaglar, and Alireza Tahbaz-Salehi, 2015, Systemic risk and stability in financial networks, *American Economic Review* 105, 564–608.

Acharya, Viral, Itamar Drechsler, and Philipp Schnabl, 2014, A pyrrhic victory? Bank bailouts and sovereign credit risk, *The Journal of Finance* 69, 2689–2739.

Acharya, Viral, and Sascha Steffen, 2015, The "greatest" carry trade ever? Understanding Eurozone bank risks, *Journal of Financial Economics* 115, 215–236.

Acharya, Viral, and Tanju Yorulmazer, 2007, Too many to fail—an analysis of time-inconsistency in bank closure policies, *Journal of Financial Intermediation* 16, 1–31.

Adrian, Tobias, and Hyun Song Shin, 2010, Financial intermediaries and monetary economics, in Benjamin M. Friedman, and Michael Woodford, eds., *Handbook of Monetary Economics*, volume 3, first edition, chapter 12, 601–650 (Elsevier).

Allen, Franklin, and Douglas Gale, 2000, Financial contagion, *Journal of Political Economy* 108, 1–33.

Allen, Franklin, and Douglas Gale, 2007, *Understanding financial crises* (Oxford University Press).

Altavilla, Carlo, Marco Pagano, and Saverio Simonelli, 2017, Bank exposures and sovereign stress transmission, *Review of Finance* 21, 2103–2139.

Alves, Nuno, Diana Bonfim, and Carla Soares, 2016, Surviving the perfect storm: The role of the lender of last resort, *Banco de Portugal Working Paper*.

Bagehot, Walter, 1873, *Lombard Street: A Description of the Money Market* (McMaster University Archive for the History of Economic Thought).

Battistini, Niccolò, Marco Pagano, and Saverio Simonelli, 2014, Systemic risk, sovereign yields and bank exposures in the euro crisis, *Economic Policy* 29, 203–251.

Becker, Bo, and Victoria Ivashina, 2018, Financial repression in the European sovereign debt crisis, *Review of Finance* 22, 83–150.

Bekaert, Geert, and Johannes Breckenfelder, 2019, The (re) allocation of bank risk, *ECB mimeo*.

Bindseil, Ulrich, Marco Corsi, Benjamin Sahel, and Ad Visser, 2017, The eurosystem collateral framework explained, *ECB Occasional Paper Series 189* .

Brownlees, Christian, and Robert F Engle, 2017, Srisk: A conditional capital shortfall measure of systemic risk, *The Review of Financial Studies* 30, 48–79.

Cabrales, Antonio, Piero Gottardi, and Fernando Vega-Redondo, 2017, Risk sharing and contagion in networks, *The Review of Financial Studies* 30, 3086–3127.

Cahn, Christophe, Anne Duquerroy, and William Mullins, 2018, Unconventional monetary policy and bank lending relationships, *Banque de France Working Paper.*

Calomiris, Charles W, Marc Flandreau, and Luc Laeven, 2016, Political foundations of the lender of last resort: A global historical narrative, *Journal of Financial Intermediation* 28, 48–65.

Cassola, Nuno, Ali Hortaçsu, and Jakub Kastl, 2013, The 2007 subprime market crisis through the lens of European Central Bank auctions for short-term funds, *Econometrica* 81, 1309–1345.

Chakraborty, Indraneel, Itay Goldstein, and Andrew MacKinlay, 2018, Housing price booms and crowding-out effects in bank lending, *The Review of Financial Studies* 31, 2806–2853.

Chodorow-Reich, Gabriel, 2014, Effects of unconventional monetary policy on financial institutions, *Brookings Papers on Economic Activity* 155–204.

Di Maggio, Marco, Amir Kermani, and Christopher Palmer, 2020, How quantitative easing works: Evidence on the refinancing channel, *Review of Economic Studies* 87, 1498–1528.

Diamond, Douglas W, and Philip H Dybvig, 1983, Bank Runs, Deposit Insurance, and Liquidity, *Journal of Political Economy* 91, 401–419.

Drechsler, Itamar, Thomas Drechsel, David Marquez-Ibanez, and Philipp Schnabl, 2016, Who borrows from the lender of last resort?, *The Journal of Finance* 71, 1933–1974.

Drechsler, Itamar, Alexi Savov, and Philipp Schnabl, 2017, The deposits channel of monetary policy, *The Quarterly Journal of Economics* 132, 1819–1876.

Elliott, Matthew, Benjamin Golub, and Matthew O Jackson, 2014, Financial networks and contagion, *American Economic Review* 104, 3115–53.

Farhi, Emmanuel, and Jean Tirole, 2012, Collective moral hazard, maturity mismatch, and systemic bailouts, *American Economic Review* 102, 60–93.

Freixas, Xavier, Bruno M Parigi, and Jean-Charles Rochet, 2000, Systemic risk, interbank relations, and liquidity provision by the central bank, *Journal of Money, Credit and Banking* 611–638.

Freixas, Xavier, Jean-Charles Rochet, and Bruno M Parigi, 2010, The lender of last resort: A twenty-first century approach, *Journal of the European Economic Association* 2, 1085–1115.

Goldstein, Itay, Alexandr Kopytov, Lin Shen, and Haotian Xiang, 2020, Bank heterogeneity and financial stability, *National Bureau of Economic Research* .

Heider, Florian, Farzad Saidi, and Glenn Schepens, 2019, Life below Zero: Bank Lending under Negative Policy Rates, *The Review of Financial Studies* 32, 3728–3761.

Ivashina, Victoria, and David Scharfstein, 2010, Bank lending during the financial crisis of 2008, *Journal of Financial Economics* 97, 319–338.

Jasova, Martina, Caterina Mendicino, and Dominik Supera, 2021, Policy uncertainty, lender of last resort and the real economy, *Journal of Monetary Economics* forthcoming.

Koijen, Ralph, François Koulischer, Benoît Nguyen, and Motohiro Yogo, 2021, Inspecting the mechanism of quantitative easing in the euro area, *Journal of Financial Economics* forthcoming.

Krishnamurthy, Arvind, Stefan Nagel, and Annette Vissing-Jorgensen, 2017, ECB policies involving government bond purchases: impact and channels, *Review of Finance* 22, 1–44.

Krishnamurthy, Arvind, and Annette Vissing-Jorgensen, 2011, Effects of quantitative easing on interest rates: Channels and implications for policy, *Brookings Papers on Economic Activity*.

Morgan, Donald P., 2002, Rating banks: Risk and uncertainty in an opaque industry, *American Economic Review* 92, 874–888.

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

Pelizzon, Loriana, Max Riedel, Zorka Simon, and Marti G. Subrahmanyam, 2020, Collateral eligibility of corporate debt in the Eurosystem, *SAFE Working Paper*.

Peydro, Jose-Luis, Andrea Polo, and Enrico Sette, 2021, Monetary policy at work: Security and credit application registers evidence, *Journal of Financial Economics* forthcoming.

Praet, Peter, 2016, *The ECB and its role as lender of last resort during the crisis* (Speech at the Committee on Capital Markets Regulation conference on the lender of last resort – an international perspective).

Rajan, Raghuram G, 2006, Has finance made the world riskier?, *European Financial Management* 12, 499–533.

Rochet, Jean, and Jean Tirole, 1996, Interbank lending and systemic risk, *Journal of Money, Credit and Banking* 28, 733–62.

Rochet, Jean-Charles, and Xavier Vives, 2004, Coordination failures and the lender of last resort: Was Bagehot right after all?, *Journal of the European Economic Association* 2, 1116–1147.

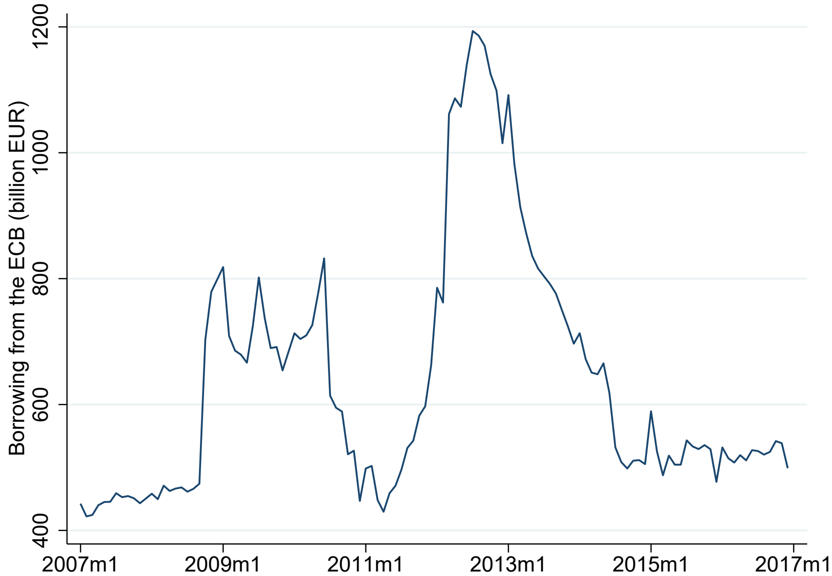
Rodnyansky, Alexander, and Olivier Darmouni, 2017, The effects of quantitative easing on bank lending behavior, *The Review of Financial Studies* 30, 3858–3887.

Stein, Jeremy C., 2012, Monetary policy as financial-stability regulation, *Quarterly Journal of Economics* 127, 57–95.

Tucker, Paul, 2009, The repertoire of official sector interventions in the financial system: Last resort lending, market-making, and capital, *Remarks at the Bank of Japan 2009 International Conference on the Financial System and Monetary Policy Implementation, Bank of Japan, Tokyo* May 27-28.

van Bekkum, Sjoerd, Marc Gabarro, and Rustom M. Irani, 2018, Does a larger menu increase appetite? Collateral eligibility and bank risk-taking, *The Review of Financial Studies* 31, 943–979.

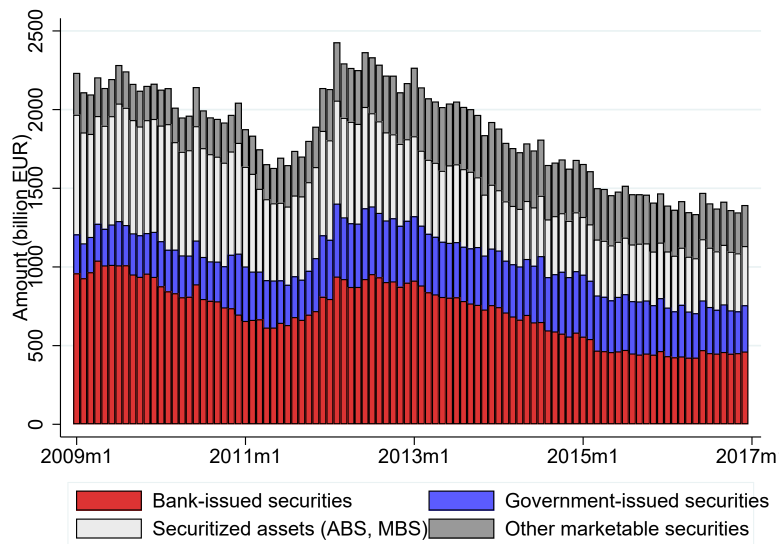
Figure 1: ECB liquidity provisions



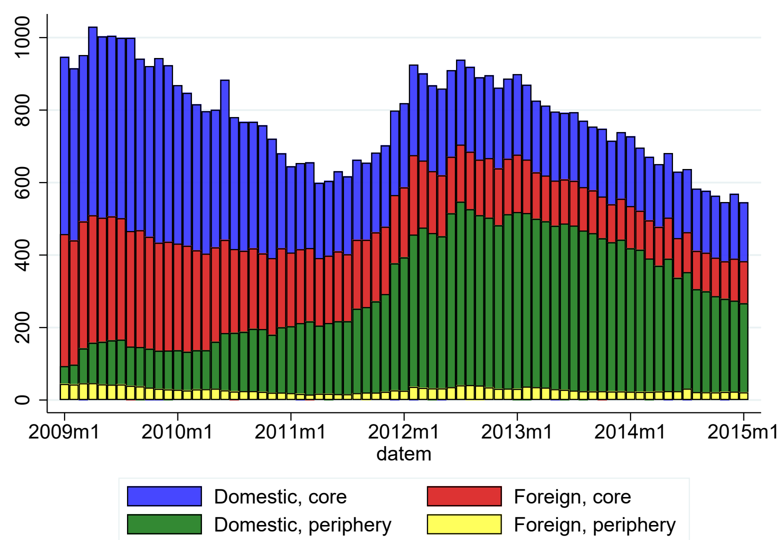
Notes: This figure shows the total bank borrowing from the ECB. The borrowing is a sum of liquidity received by weekly main refinancing operations (MRO) and all longer-term refinancing operations (all LTRO and targeted-LTRO facilities) of all banks in the euro area. Reported in billion EUR.

Figure 2: Collateral pledging with the ECB

(a) By Security Type



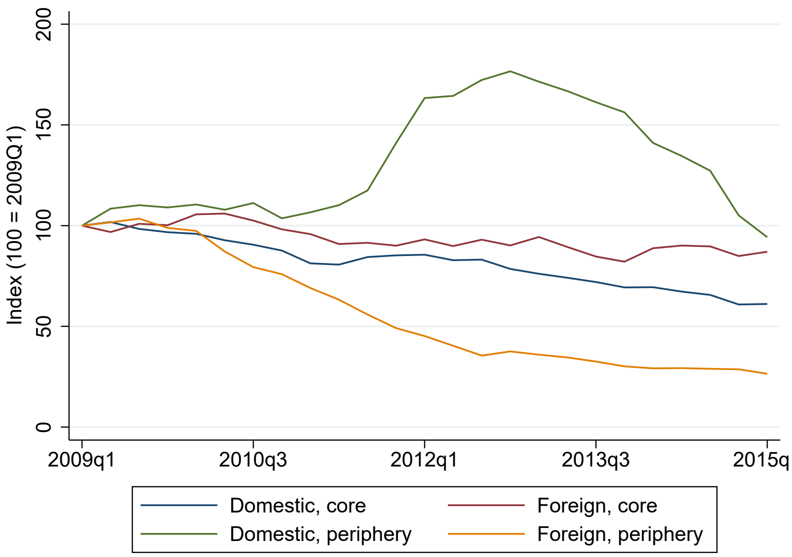
(b) Bank Bonds: Domestic vs Foreign



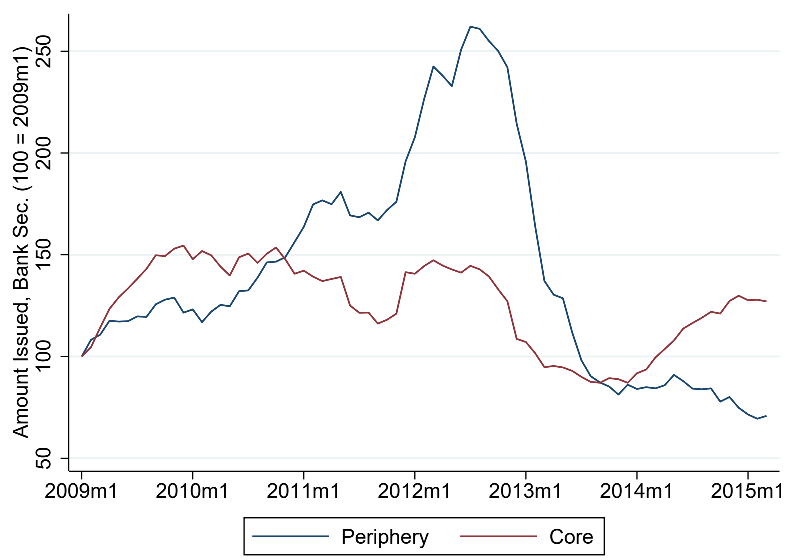
Notes: This figure summarizes the securities pledged as collateral with the ECB by all banks in the euro area. Reported in book values in billion EUR. Panel (a) summarizes the composition of marketable securities; Panel (b) displays the composition of bank-issued securities across core and periphery euro area countries.

Figure 3: Holding and issuances of bank bonds

(a) Holding

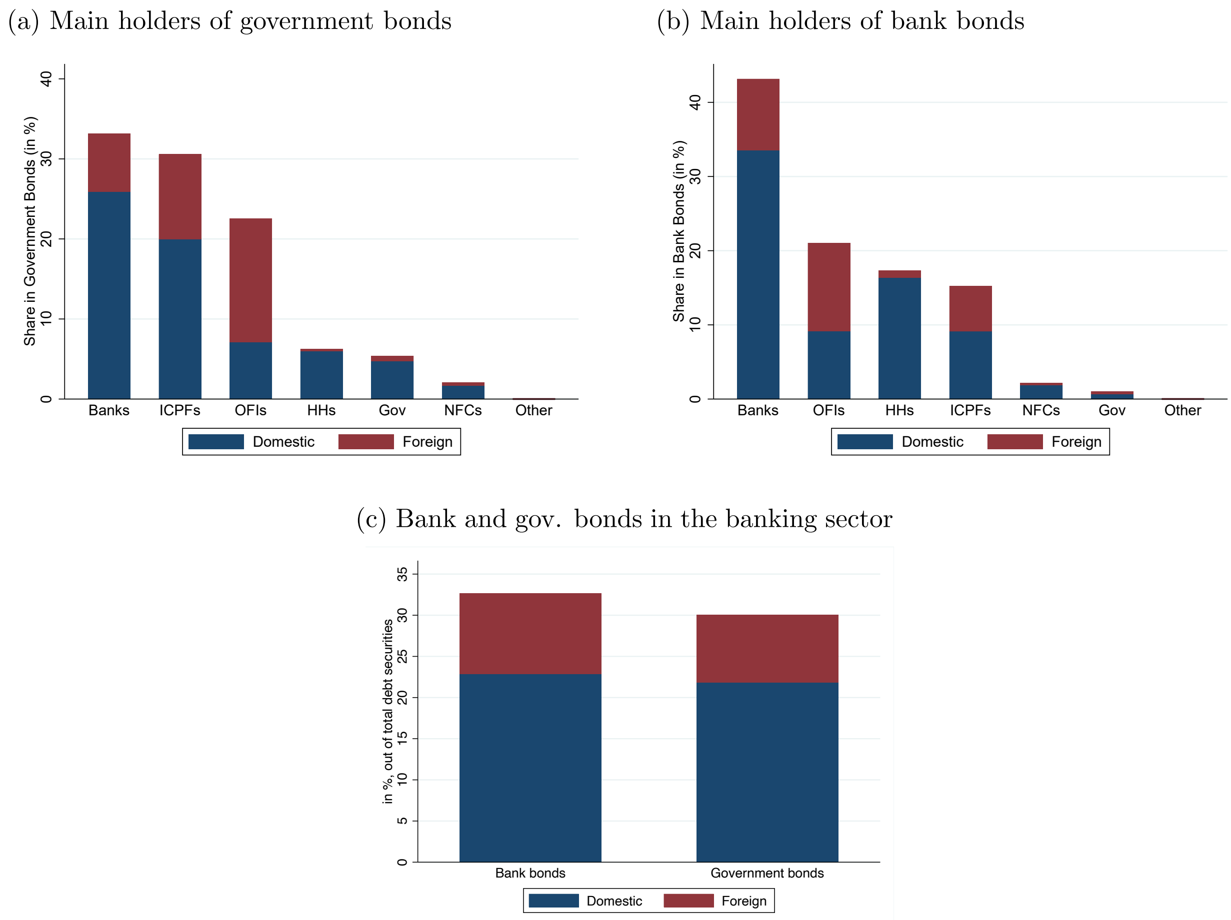


(b) Issuances



Notes: This figure summarizes the holdings (Panel (a)) and issuances (Panel (b)) of bank bonds by all banks in the euro area. Issuances represent 12 month moving average. All series are indexed to 2009Q1.

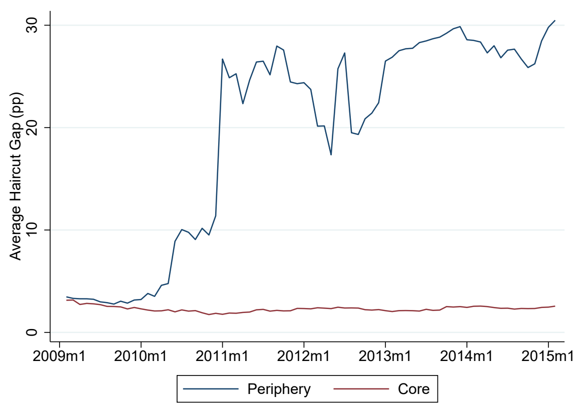
Figure 4: Security holdings by sectors



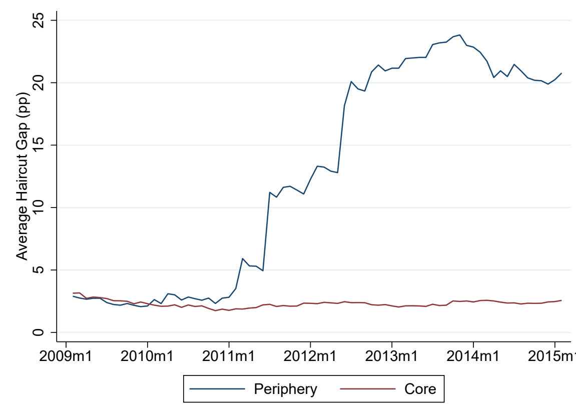
Notes: This figure shows the key holders of government and bank securities. Panels (a) and (b) divide the holdings across key institutional sectors: banks, insurance companies and pension funds (ICPFs), other financial institutions (OFIs), households (HH), central government (Gov), non-financial corporations (NFC) and other. The values are reported in percent to total value outstanding. Panel (c) reports the total bank holdings of bank or government securities as a fraction of all bonds held by the banking sector. All reported figures refer to Q1 2014. Source: Security Holding Statistics.

Figure 5: Average haircut gap for securities issued in core and periphery

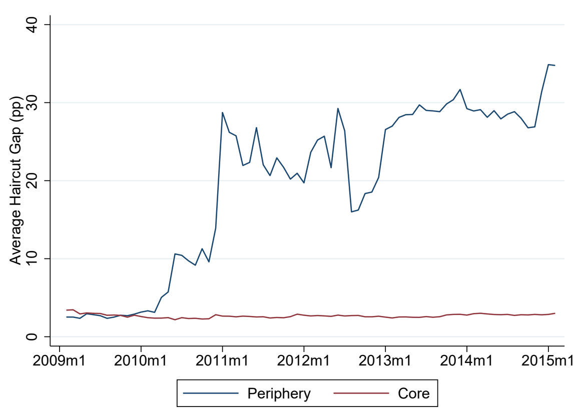
(a) All countries, Bank and government securities



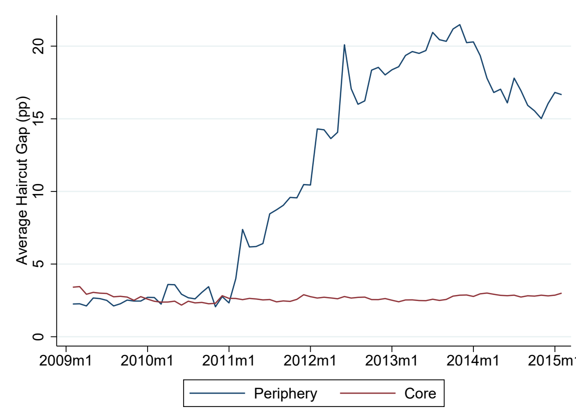
(b) Excl. Greece, Bank and government securities



(c) All countries, Bank securities



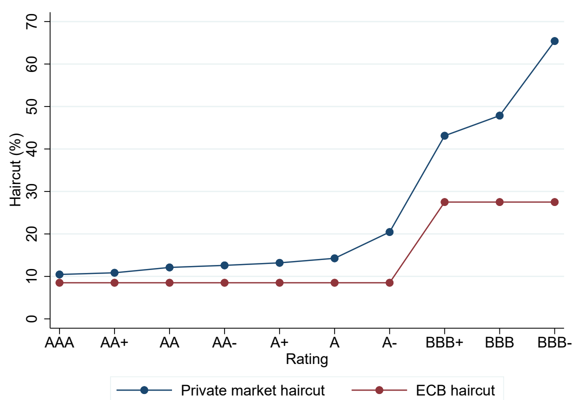
(d) Excl. Greece, Bank securities



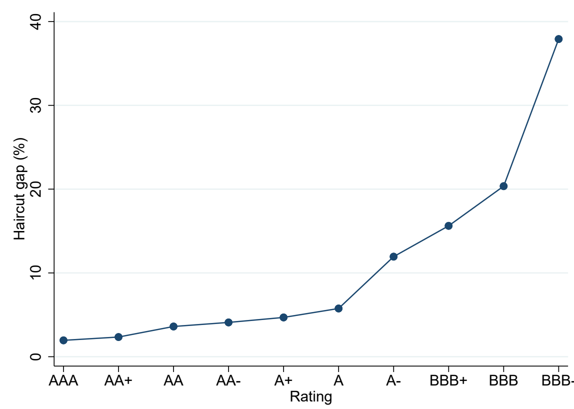
Notes: This figure shows the evolution of the haircut gap over time across periphery and core countries. Average haircut gap is reported in percentage points on the vertical axis.

Figure 6: Identification (1)– Kinks and jumps

(a) Private market vs ECB haircuts



(b) Haircut gap



Notes: This figure illustrates the identification strategy using kinks and jumps using average haircut valuations of uncovered bank bonds with residual maturity 1-3 years and fixed coupon. Panel (a) shows 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.

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
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
Rating	numerical scale	477,104	4.1	2.7

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)
$\text{HaircutGap}_{s,t-1}$	0.00369***	0.00295***	0.00522***
	(0.000308)	(0.000347)	(0.000594)
$\text{HaircutGap}_{s,t-1} \times \text{Bank Bonds}_s$	0.00634***	0.00567***	0.00307***
	(0.000780)	(0.000788)	(0.000848)
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 regressions related to security pledging, as described in equation (3). 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 3: Systemic risk: home bias
Full Sample

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}$	0.0169***	0.0159***	0.0151***
	(0.00146)	(0.00146)	(0.00147)
$\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,b}$	0.00147	0.000374	-0.000408
	(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 security pledging, as described in equations (4). 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: core vs periphery
Full Sample

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(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 security pledging, as described in equation (5). 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: bond price correlation
Full Sample

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(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	1112014	1112014	1112014
R^2	0.812	0.812	0.812

Notes: This table presents coefficients from regressions related to security pledging, as described in equations (6). Controls: 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

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(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)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$ 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 security pledging, as described in equation (7). 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-holding
Full Sample

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{ExistRelation}_{s,b,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0566***	0.0581***	0.0577***
	(0.00708)	(0.00720)	(0.00727)
$\text{ExistRelation}_{s,b,t-1} \times \text{HaircutGap}_{s,t-1}$	-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 security pledging, as described in equation (8). 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: home bias
Two Identifications

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	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	No	No
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 security pledging, as described in equations (4) for the two identification strategies. 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: core vs periphery
Two Identifications

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	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	No	No
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 security pledging, as described in equation (5) for the two identification strategies. 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: bond price correlation
Two Identifications

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	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	No	No
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 coefficients from regressions related to security pledging, as described in equations (6) for the two identification strategies. 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
Two Identifications

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$				
	Strategy 1: Kinks and Jumps			Strategy 2: Binding Downgrades	
	(1)	(2)	(3)	(4)	(5)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1} \times \text{SRISK}_{b,t-1}$	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)
$\text{SRISK}_{b,t-1} \times \text{HaircutGap}_{s,t-1}$	-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	No	No
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 coefficients from regressions related to security pledging, as described in equations (7) for the two identification strategies. 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: Issuance of bank bonds

Panel (a): Security-level analysis

	log(value issued)$_{s(t)}$			
	(1)	(2)	(3)	(4)
HaircutGap$_{s(t-1)}$	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	No	No
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(value outstanding)$_{b,t}$			
	(1)	(2)	(3)	(4)
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	No
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 coefficients from regressions related to security issuance, as described in equations (9) and (10). 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.

A Appendix

A.1 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 assets class, ratings (respective rating agencies Fitch, Moody's, S&P, DBRS as well as their combinations), 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. All rating variables (respective ratings, median, worst, best) are below the minimal depth threshold.

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.

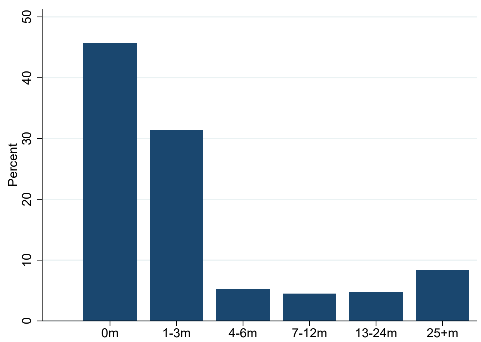
Similarly to the random forest, the BMA estimated regression models with different subsets of variables. Again, we start by considering a similarly comprehensive set of variables (while unlike random forest some combinations are dropped due to collineraity) BMA uses model composition Markov Chain Monte 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 unimputed sample (from the clearing houses) are reported in Appendix Table A3.

A.2 Additional Tables and Figures

Figure A1: Pledging and holding

(a) Timing of pledging of newly issued bonds



(b) Ratio of amount pledged to held

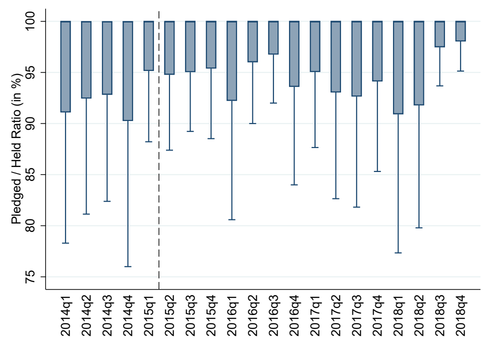


Table A1: Systemic risk and size of issuing bank

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(1)	(2)	(3)
$\text{HaircutGap}_{s,t-1}$	0.00780***	0.00688***	0.00635***
	(0.00155)	(0.00154)	(0.00155)
$\text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	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)
$\text{LargeBank}_{s,t-1} \times \text{Domestic}_{s,b} \times \text{HaircutGap}_{s,t-1}$	0.0345***	0.0344***	0.0352***
	(0.00423)	(0.00424)	(0.00425)
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 coefficients from regressions related to security pledging, as described in equation (7). 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 A2: Systemic risk and equity ratio of issuing bank

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$		
	(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 coefficients from regressions related to security pledging, as described in equation (7). For robustness, the dummy variable SRISK is replaced with a dummy LargeBank which takes the value of 1 if the issuing bank size is the top decile of the bank size distribution in the respective country and zero 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 A3: Robustness to haircut gap measures

	$\frac{\text{value pledged}_{s,b,t}}{\text{value outstanding}_s}$			
	(1)	(2)	(3)	(4)
	Random Forest	BMA	Linear regression	Unimputed data
$\text{HaircutGap}_{s,t-1} \times \text{Domestic}_{s,b}$	0.0151***	0.0163***	0.0126***	0.0281***
	(0.00147)	(0.00111)	(0.00124)	(0.00598)
$\text{HaircutGap}_{s,t-1} \times \text{Foreign}_{s,b}$	-0.000408	0.00192*	0.00123	-0.0372***
	(0.00135)	(0.00100)	(0.00108)	(0.00437)
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	106,360
R^2	0.869	0.838	0.839	0.924

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