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## **COLLATERAL, CENTRAL BANK REPOS, AND SYSTEMIC ARBITRAGE**

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Woschitz

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## Abstract

Central banks are under increased scrutiny because of the rapid growth in, and composition of, their balance sheets. Therefore, understanding the processes that shape these balance sheets and their consequences is crucial. We contribute by studying an extensive dataset of banks' liquidity uptake and pledged collateral in central bank repos. We document systemic arbitrage whereby banks funnel credit risk and low-quality collateral to the central bank. Weaker banks use lower quality collateral to demand disproportionately larger amounts of central bank money (liquidity). This holds both before and after the financial crisis and may contribute to financial fragility and fragmentation.

JEL Classification: G12, G21, E42, E51, E52, E58

Keywords: Collateral, repo, systemic arbitrage, central bank, collateral policy, banks, liquidity, interbank market, financial stability, financial fragmentation

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# COLLATERAL, CENTRAL BANK REPOS, AND SYSTEMIC ARBITRAGE <sup>1</sup>

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## Abstract

### Collateral, central bank repos, and systemic arbitrage

Central banks are under increased scrutiny because of the rapid growth in, and composition of, their balance sheets. Therefore, understanding the processes that shape these balance sheets and their consequences is crucial. We contribute by studying an extensive dataset of banks' liquidity uptake and pledged collateral in central bank repos. We document systemic arbitrage whereby banks funnel credit risk and low-quality collateral to the central bank. Weaker banks use lower quality collateral to demand disproportionately larger amounts of central bank money (liquidity). This holds both before and after the financial crisis and may contribute to financial fragility and fragmentation.

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# 1. Introduction

Central banks have come under increasing scrutiny in recent years, in part because of the growth in, and the composition of, their balance sheets. Even central bankers themselves are concerned. For example, Thomas Jordan, President of the Swiss National Bank, has expressed the view that “[a]s a result of the measures implemented during the crisis, central banks took much more risk onto their balance sheets, which could potentially lead to substantial losses” (Jordan, 2012). Klaas Knot, Governor of the Dutch Central Bank and a member of the Governing Council of the European Central Bank (ECB), expands on this: “. . . central banks’ balance sheets are becoming more and more exposed to economic risk and political pressure. Eventually, this may result in substantial amount of negative capital in a central bank’s balance sheet. This is undesirable, because it could undermine a central bank’s credibility. . .” (Knot, 2013). Nyborg (2015 and 2016a) argues that central bank collateral policies contribute to these trends, which are a risk to financial stability, and provides evidence from the euro area that central bank balance sheets have expanded into increasingly large fractions of lower quality collateral over time. He also discusses various ways that collateral policies may undermine market discipline and create distortions in the real economy. This narrative contrasts with the view articulated by Cochrane (2014a and 2014b) and Greenwood, Hanson, and Stein (2016) that larger central banks may help financial stability. However, these authors do not focus attention on the processes that shape the composition of central bank balance sheets. It is, therefore, important to understand more about these processes and their implications.

This paper contributes to this agenda by focusing on how the interrelationship between the central bank and banks can ultimately affect the exposure of the central bank. In particular, we use data from the euro area to document what one can think of as systemic arbitrage on the part of banks vis-à-vis the central bank. This involves funneling credit risk and low quality collateral from banks to the central bank and is facilitated by central bank policies.<sup>1</sup> Systemic arbitrage may be a contributing factor to financial instability because it lowers the quality of the central bank’s balance sheet and impairs the functioning of the

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<sup>1</sup>The idea of systemic arbitrage and that the Eurosystem’s collateral framework is susceptible to it is introduced in Nyborg’s (2016a) in-depth study of central bank collateral frameworks. See Nyborg (2015) for a summary.

interbank market. We also raise the issue in this paper that systemic arbitrage may be a contributing factor to the problem of financial fragmentation in the euro area (see, e.g., European Central Bank, 2012 or 2014, Van Rixtel and Gasperini, 2013, or Cline, 2014). In other words, the processes that shape central bank balance sheets may also affect other areas of the financial system.

The interaction between central banks and banks revolves around the need for banks to satisfy reserve requirements and the provisioning of central bank money, or liquidity, by the central bank to banks. Importantly, liquidity is provided to banks either through outright purchases of securities or, as has been more common in the euro area, repurchase agreements (repos). The collateral central banks receive and the credit risk they may take on directly affect their balance sheet exposures. In this paper, we study the relation between liquidity uptake in Eurosystem repos (also referred to in the paper as Eurosystem credit), the quality of pledged collateral, and financial health at the individual bank level.<sup>2</sup> The data is furnished by the Deutsche Bundesbank for the purpose of this study and covers all German banks over the period 1/2006–10/2010. Our finding on systemic arbitrage is generic in that it describes the data before and after the onset of the financial crisis.

To put the data in context, note first that the ECB conducts its open market operations predominantly through refinancing operations, which inject central bank money through repos. Banks can also borrow against collateral through the marginal lending facility (discount window). In these transactions, which we collectively refer to as Eurosystem repos, central bank money is provided against a highly diverse set of eligible collateral, ranging from government bonds to asset-backed securities (ABSs) and even non-marketable assets such as credit claims. The set of eligible marketable collateral includes an astounding number of ISINs, typically being in the range of 30,000 to 40,000.<sup>3</sup> The refinancing operations and the lending facility are open to all banks in the euro area, including branches of foreign banks, on equal terms. This contrasts with the primary dealer system employed, for example, by the Federal Reserve System in the US. The wide range of eligible collateral and the inclusivity of the operations make for an environment in which systemic arbitrage

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<sup>2</sup>The liquidity uptake, or credit, data also includes emergency liquidity assistance (ELA). The Eurosystem is the system of central banks in the euro area, comprised of the European Central Bank and the individual national central banks.

<sup>3</sup>See <https://www.ecb.europa.eu/paym/coll/html/index.en.html>. Eberl and Weber (2014) and Nyborg (2016a and 2016b) provide detailed discussions on the set of eligible collateral.

can potentially fester.

The scope for banks to arbitrage the system was substantially widened as of October 8, 2008, less than one month after Lehman Brothers' bankruptcy, with the introduction of the full allotment policy. Under this emergency policy, which is still in force, banks receive the full quantity they ask for in refinancing operations, subject to pledging sufficient collateral. All banks pay the same repo rate, regardless of how much they receive. Collateral eligibility rules were also relaxed the same month. Previously, the ECB operated with a liquidity neutral policy, whereby it would inject through its operations the liquidity banks would need in aggregate to satisfy reserve requirements and other liquidity needs.<sup>4</sup> Whereas a liquidity neutral policy encourages trade among banks, the full allotment policy allows banks to bypass the discipline of the markets. This unconventional monetary policy has been accompanied by a substantial increase in the Eurosystem's consolidated balance sheet as well as large excess reserves within the banking sector (see, e.g., Nyborg, 2016a).

Against this backdrop, we use our data in two different, but related ways. First, we study aggregate time patterns in liquidity uptake and collateral usage in Eurosystem repos by German banks. We document that they use increasingly more German domiciled collateral and less so-called PIIGSC collateral over time.<sup>5</sup> Overall, as the crisis progresses, German banks become less reliant on lower quality collateral. In addition, their liquidity uptake drops, even as total Eurosystem liquidity injections rise under the full allotment policy. These findings are consistent with financial fragmentation in the euro area along national lines. The evidence also means that German banks' aggregate position vis-à-vis the Eurosystem strengthened, in the sense that their contribution to overall Eurosystem risk fell.

Our second, and main, piece of analysis exploits the panel structure of the data. In this analysis, we gauge collateral quality by measures such as haircuts, default probabilities, duration, and the ECB's own classification of assets into liquidity categories. Financial health is captured by write-offs and provisions, equity as a fraction of assets, and return on assets. In our regressions, we control for deposit flows from banks and non-bank entities. Regardless of what time period we look at – pre-crisis, early stage of crisis, or full allotment

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<sup>4</sup>The phrase liquidity neutral to describe the ECB's former policy was first used by Nyborg, Bindseil, and Strebulaev (2002). See also Bindseil, Nyborg, and Strebulaev (2009) and Bindseil (2014) for details.

<sup>5</sup>PIIGSC is an acronym for Portugal, Ireland, Italy, Greece, Spain, and Cyprus.

– we find that banks in worse financial health and with lower quality collateral (more risky and illiquid) have larger liquidity uptake (borrow more) in Eurosystem repos relative to their assets and reserve requirements. In short, the banking sector passes an overweight of high credit risk and low quality collateral on to the balance sheet of the central bank. Credit risk is notably not taken into account in Eurosystem repos, neither in the repo rate nor in collateral haircuts. Thus, systemic arbitrage is an appropriate terminology for our findings since it means that banks, in aggregate, keep the better collateral and lower credit risk among themselves, without this affecting the interest they pay to the central bank or the amount they borrow.

The finding that banks in poor financial health have relatively large liquidity uptakes in Eurosystem repos is somewhat stronger under the full allotment policy. In addition, the introduction of this policy sees a marked increase in the participation of small cooperative banks in relatively poor financial health. This suggests that the full allotment policy provides support, or indirect bailouts, to weaker banks, as argued by Abbassi, Bräuning, Fecht, and Peydró (2014) and Nyborg (2016a). We also find that deposit flows stop having an impact on individual banks' borrowings from the central bank after the introduction of this policy. It seems that the role of markets in the allocation of liquidity across banks is obliterated under full allotment, even in a relatively healthy country such as Germany.

That banks with worse collateral have larger Eurosystem liquidity uptakes likely reflects the efficient usage of collateral by banks. It is consistent with the idea expressed by Nyborg, Bindseil, and Strebulaev (2002) that Eurosystem haircuts do not equilibrate the opportunity costs associated with using different collateral. In particular, our finding is suggestive of lower quality collateral having lower opportunity costs. There are several reasons as to why this may be the case.

First, lower quality collateral may have low Eurosystem haircuts relative to their levels of risk and illiquidity. This could be by design, to help weaker banks, or could arise from the fact that Eurosystem haircuts are rarely revised and therefore do not reflect market conditions (Nyborg, 2016a). Biases in the collateral framework may therefore develop over time as market conditions change.

Second, lower quality collateral also has limited use outside of Eurosystem operations. For example, central counterparty (CCP) repos lock out many securities that are eligible to be used in repos with the Eurosystem. As an example, while the Eurosystem accepts

30,000–40,000 different ISINs, Eurex only accepts 7,000–8,000 of these in their popular Eurex GC Pooling ECB basket contracts. It is especially lower quality collateral that is excluded.<sup>6</sup>

Third, as shown by Ewerhart and Taping (2008), two-way default risk gives rise to a preference for higher quality collateral in bilateral repos between banks and, by implication, lower quality collateral in repos with the central bank. The logic is that while the cash provider in a repo is protected by higher haircuts, this exposes the cash taker to larger losses should the cash provider fail to return the collateral. Thus, higher quality collateral, for which haircuts are smaller, reduces aggregate default costs.<sup>7</sup> As a result, using lower quality collateral in repos with the central bank entails lower opportunity costs, since banks benefit by “saving” higher quality collateral for bilateral repos or other transactions they may wish to engage in. Of course, doing this is only possible if the central bank accepts a wide range of collateral, as is the policy in the euro area.

To summarize, in a system where the central bank injects liquidity against a heterogeneous set of collateral, we would expect the central bank to receive the collateral with the lowest opportunity costs to banks. There are institutional as well as theoretical reasons to expect this to be the collateral that is most risky and illiquid. This is what seems to be happening in our data. Banks also appear to exploit the credit risk loophole that higher credit risks do not pay higher rates in Eurosystem repos.

The credit risk loophole also means that a bank has an incentive to pledge collateral that is likely to default when the bank itself defaults. Doing so, the bank benefits from a risk premium that is paid for a risk that is irrelevant to the bank. In other words, the subsidy from the credit risk loophole is larger when weak banks use worse collateral and, especially, collateral that is likely to fall in value in states of the world where the bank is likely to default. Systemic arbitrage by banks in aggregate may also reflect optimization with respect to this – what we more specifically may call the correlated default loophole. Consistent with this view, we find evidence in the cross-section that banks in worse financial health tend to have worse collateral. We also find that banks increasingly make use of collateral issued by themselves or a related party as the crisis evolves and the rules are relaxed with

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<sup>6</sup>See <http://www.eurexrepo.com/repo-en/products/gcpooling/> (January 20, 2015). Eurex acts as a central counterparty (CCP) in these contracts. See Nyborg (2016a) for further details on collateral in Eurex contracts versus collateral in Eurosystem operations.

<sup>7</sup>The argument assumes that default costs are positively related to losses in default.

respect to such “own use” of collateral (Nyborg, 2016a) under the full allotment policy. In Section 6, we discuss how the credit risk/correlated default loophole may reduce market discipline in the interbank market for liquidity and also be a contributing factor to the well-documented financial fragmentation experienced in the euro area that our evidence is also consistent with.

The rest of the paper is organized as follows. Section 2 provides further institutional background relevant for this paper. It also describes the main data and reports on aggregate time patterns in the data with respect to liquidity uptake and collateral usage by German banks. Section 3 sets up the panel analysis by describing the data and variables that will be used as well as providing descriptive statistics. Sections 4 and 5 then present the panel regressions. Section 6 provides discussion and Section 7 concludes.

## **2. Overview**

This section provides an overview of key institutional features relating to Eurosystem liquidity injections, banks’ collateral pools, collateral values, and haircuts. It also describes the main data in this paper and provides aggregate statistics on German banks’ collateral pool holdings and liquidity uptake over time. Broad euro area statistics on liquidity uptake, or credit, are also provided. The aggregate statistics shed light on the increasing national fragmentation in the euro area as the crisis unfolded. It also serves as background to the more in-depth panel analysis, using additional bank level data, in Sections 3, 4, and 5.

### **2.1 Central bank liquidity injections and banks’ collateral pools**

As touched on in the Introduction, the ECB injects liquidity into the banking sector primarily through its refinancing operations. There are two main types, namely the main refinancing operations (MROs) and the longer term refinancing operations (LTROs). Until September 19, 2007, the MROs were the main source of central bank money in the euro area. After that time, the LTROs have been more important (Nyborg, 2016a). Over the 1/2006–10/2010 sample period of this paper, the maturities of the LTROs range from one month to one year and those for the MROs always equal one week. Until October 7, 2008, the size of these operations were determined according to the ECB’s liquidity neutral policy (see the Introduction). Reserve maintenance periods are timed to coincide with every

second Governing Council meeting and cover approximately one month. Within a maintenance period, banks need to hold a daily average level of reserves determined by their short term liabilities at the end of the calendar month ending before the start of the previous maintenance period. From October 8, 2008, the MROs and LTROs have been held under the full allotment policy, where banks receive the quantity of liquidity they ask for at the policy rate. The only constraint is that banks need to post sufficient collateral to cover the quantity they receive.

There are two standing facilities. Banks can obtain liquidity from the marginal lending facility (discount window) and place liquidity in excess of reserve requirements at the deposit facility. Before the financial crisis, these rates were always at a spread of 100 basis points (bps) above or below, respectively, the ECB's policy rate. This spread was lowered to 50 bps after the Lehman bankruptcy and raised again to 75 bps in May 2009, where it has remained for the duration of the sample period. Borrowings at the marginal lending facility are overnight, but can be rolled over indefinitely subject to having sufficient collateral.

When a bank obtains liquidity from the Eurosystem through the operations and standing facility described above, the actual repo is with its national central bank. However, the terms, including rates, eligible collateral, and haircuts, are set by the ECB.<sup>8</sup> In Germany, each bank has an eligible collateral inventory account, or collateral pool, with the Deutsche Bundesbank. Under the pooling system, collateral is not earmarked for particular transactions.<sup>9</sup> Banks can move eligible collateral in and out of their pool, with the only constraint being that at the end of each day, the total collateral value of a bank's pool needs to be at least equal to a bank's total gross Eurosystem liquidity uptake.<sup>10</sup> Banks therefore need to pay heed to the ECB's system for determining collateral values.

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<sup>8</sup> By "eligible collateral" we mean collateral that is accepted in the Eurosystem's refinancing operations and marginal lending facility. Until December 31, 2006, the Eurosystem operated with a Tier 1 and Tier 2 eligible collateral system. Whereas Tier 1 collateral were set by the ECB; Tier 2 assets were to some extent under the control of national central banks, though subject to approval by the ECB. European Central Bank (2003) is the last legal document that defines the rules under the two-tier system. With European Central Bank (2005) and European Central Bank (2006) the ECB introduced the single list framework in two steps.

<sup>9</sup> While national central banks in the Eurosystem are generally free to choose whether to pool or earmark collateral, only the Bank of Spain allows banks to earmark collateral for central bank operations (Bank for International Settlements, 2013).

<sup>10</sup> So usage of the deposit facility does not free up collateral.

## 2.2 Collateral values and haircut policy

The *collateral value* of one unit of collateral  $i$  on day  $t$  is given by

$$V_{it} = (1 - h_{it})P_{it}, \quad (1)$$

where  $h_{it}$  is the Eurosystem haircut and  $P_{it}$  is the market price of the collateral.<sup>11</sup> A bank can borrow a maximum of  $V_{it}$  on day  $t$  from the Eurosystem against one unit of collateral  $i$ .

Eurosystem haircuts are set by the ECB according to a rigid scheme that is rarely modified. Table 1 shows that over the five year sample period of this paper, the Eurosystem’s haircut scheme for marketable collateral was updated only once, namely on October 24, 2008. Panel A covers the rules that applied up to October 24, 2008, and Panel B covers the period thereafter to the end of the sample period.<sup>12</sup> As seen, some haircut updates announced on October 23, 2008 came into force two days afterwards and others on February 1, 2009, implying that parts of Panel A applied until that later date.

**Insert Table 1 here.**

Table 1 reveals that a collateral’s haircut is determined by four main factors. First, it depends on the collateral’s type, e.g., central government bond, local government bond, covered bond, unsecured bond, or ABS. Each type is placed in a “liquidity category” by the ECB, with increasingly higher liquidity categories representing types of collateral that are viewed as intrinsically less liquid (and arguably also more risky) and thus receive higher haircuts, *ceteris paribus*. Among standard marketable collateral, government bonds have the lowest haircuts and ABSs the highest. The haircuts of non-marketable collateral (not shown in Table 1) are higher yet again.<sup>13</sup>

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<sup>11</sup>In practice, a theoretical price is often used instead of a market price. See Nyborg (2016a and 2016b) for further discussion and evidence.

<sup>12</sup>For part of the period covered by Panel A, the ECB operated with a two-tier system for eligible collateral (see footnote 8). This was replaced with a harmonized “single list” of eligible collateral on January 1, 2007. Under this system, collateral is divided into marketable and non-marketable collateral. Panel B: At the time they were introduced, many of the adjustments to eligibility criteria and haircuts in Panel B were labeled as being temporary. Nevertheless, most of these modifications are still in place today, though haircuts have in many cases changed further. Nyborg (2016a) provides a comprehensive overview of the development of these and other issues relating to the Eurosystem’s collateral framework. Our Table 1 corresponds to the marketable collateral parts of his Tables 5.1 and 5.2.

<sup>13</sup>A comprehensive schedule of haircuts is provided in Nyborg (2016a).

Second, haircuts are increasing in the collateral’s residual maturity, *ceteris paribus*. Third, haircuts depend on the type of coupon; fixed, zero, or floating. Within each liquidity category and residual maturity bucket, the haircuts of fixed coupon collateral are less than or equal to zero coupon collateral. Both residual maturity and coupon type relate to the concept of bond duration. Table 1 shows that haircuts are (weakly) increasing in duration. More generally, haircuts are increasing in risk and illiquidity (as assessed by the ECB). A collateral’s Eurosystem haircut is therefore a good candidate for a simple measure of relative collateral quality at a given point in time. This will be explored further in Section 4.2.

In Panel A, the lowest haircut, 0.5%, is for collateral of Liquidity Category I (central government and central bank bonds) with residual maturity of less than one year. The largest, 25%, is for inverse floaters with more than 10 years to run.

Ratings are conspicuously absent from Panel A. Until October 2008, the haircuts of eligible collateral were not affected by ratings. However, a rating of A– (on the S&P scale) or higher was required for collateral eligibility.<sup>14</sup>

The main change introduced in Panel B is that the minimum ratings requirement is lowered to BBB–. A rating in the BBB– to BBB+ range adds 5% to the baseline haircut of paper rated A– or higher. Panel B also sees the introduction of a fifth liquidity category.<sup>15</sup> The general point remains that illiquidity and risk increase Eurosystem haircuts and thereby also decrease collateral values.

## 2.3 Data: Collateral pools and liquidity uptake

Our main data consists of detailed information on individual German banks’ collateral pools and their net Eurosystem liquidity uptake, or credit. The latter is defined as the total amount of borrowings a bank has outstanding on a given day from the Eurosystem, with these borrowings coming from three possible sources, namely (i) refinancing operations, (ii) the marginal lending facility, and (iii) emergency liquidity assistance, if any. The data has been made available by the Deutsche Bundesbank for the purpose of this research project and includes all banks in their system.

The collateral data consists of various collateral characteristics (to be described below)

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<sup>14</sup>Unless otherwise specified, all ratings in this paper are on the S&P scale.

<sup>15</sup>Unsecured bank bonds (labeled credit institution debt instruments) is separated out from traditional pfandbriefen (covered bonds).

of individual banks' collateral pools on 667 irregularly spaced days over the period January 18, 2006 to December 31, 2010. The sampling frequency increases towards the end of the sample. There is at least one sample day in each of the 60 reserve maintenance periods covered by the sample period. Unique bank codes allow us to follow individual banks over time and merge the collateral data with other bank characteristic data (to be discussed in Section 3). Banks' liquidity uptake is part of the collateral data file as are their reserve holdings with the central bank.

The data comprises 1,588 banks that have collateral in their pool on at least one of the 667 sample days, for a total of 813,576 bank-day observations. For each bank-day, we have market and collateral values broken down by the collateral's type and country of origin.<sup>16</sup> In total we observe 4,323,775 bank, day, country of origin, and type of collateral combinations.

The collateral types relate to the liquidity categories in Table 1. In particular, the data breaks collateral into: debt instruments issued by central governments and central banks, local and regional governments, agencies and supranational institutions, non-financial corporations, and financial corporations. The latter is further partitioned into jumbo covered bank bonds, traditional covered bank bonds, unsecured credit institution instruments, and other financial corporation debt instruments. The last two categories are further broken down into asset-backed securities and non-marketable collateral.<sup>17</sup>

For each bank-day, we have the quantity weighted averages of the underlying collateral for the following variables: haircut, liquidity category, duration, default probability according to the Bundesbank's own model, own-use (of collateral), and the Herfindahl-Hirschman index (HHI) based on either the asset class or issuer group of the collateral.<sup>18</sup> The weighting

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<sup>16</sup>The country of origin is the place of establishment of a collateral's issuer. This can either be a European Economic Area (EEA) or a Group-of-Ten (G-10) country.

<sup>17</sup>Non-marketable collateral is either fixed-term deposits from eligible counterparties, credit claims (bank loans) or non-marketable retail mortgage-backed debt instruments. However, our data does not split up the non-marketables into these sub-categories.

<sup>18</sup> Asset class (for the purpose of the HHI) is one of the following: (1) bond, (2) medium-term note, (3) (treasury) bill, commercial paper, or certificate of deposit, (4) commercial bill (e.g. trade bill, bill of exchange), (5) other assets, (6) Jumbo Pfandbriefe-style, (7) Traditional Pfandbriefe-style, and (8) other securitized assets/ABS/MBS. Issuer group is one of the following: (1) central bank, (2) central government, (3) corporate and other issuers, (4) credit institution (excluding agencies), (5) regional/local government, (6) supranational issuer, (7) agency - non credit institution, and (8) agency - credit institution.

is by collateral value.

Own-use refers to collateral issued by an entity with which the bank that holds it in its pool has close links, as defined in the official, legal documentation.<sup>19</sup>

Finally, banks are labeled by the Bundesbank as belonging to one of the following sectors, or bank types: Savings banks and their central banks, the Landesbanken; cooperatives and cooperative central banks; private banks (“regular” banks); branches of foreign banks; private loan banks; special purpose banks, and Bausparkassen (building societies). We refer the reader to Hackethal (2004) or Fecht, Nyborg, and Rocholl (2011) for a discussion of the roles different bank types play in the overall German banking system. The main types can be said to be savings banks, cooperatives, and the “regular” private banks.

## 2.4 Aggregate patterns over time: Collateral and liquidity uptake

For the purposes of this section, we prune the raw data of 813,576 bank-day observations as follows: First, we exclude 7,029 bank-days with missing country of collateral origin data. Second, we drop 2,544 bank-days with recorded negative reserve holdings or haircuts. Third, we also drop 5,028 bank-days without official bank type information or that relate to a change of bank type. In particular, we drop a bank from any of the five sub-periods we study (defined below) if it has changed its type within that period. The final sample comprises 798,975 bank-days (98.2% of the initial sample).

For each sample day, we work with the aggregate collateral pool and liquidity uptake (credit) over all banks. To gauge the liquidity uptake of German banks as compared to that of the rest of the euro area, we also have downloaded weekly data from the ECB’s Statistical Data Warehouse on the aggregate outstanding credit to euro area banks.<sup>20</sup>

Besides aggregate collateral values and liquidity uptake, we also report on portfolio weights in the aggregate collateral pool for the following seven categories: (i) Government,

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<sup>19</sup>Entities A and B are said to have close links (i) if one of them directly or indirectly owns or controls 20% or more of the capital or voting rights of the other, or (ii) a third party directly or indirectly owns or controls the majority of the capital or voting rights of both A and B (European Parliament and Council, 2000). See European Central Bank (2005), footnote 50, and European Central Bank (2010) or, for further discussion, Nyborg (2016a).

<sup>20</sup>Downloaded from <http://sdw.ecb.europa.eu/browse.do?node=bbn129> (January 20, 2015).

central bank, agency, or supranational institution bonds; (ii) Covered bonds; (iii) Corporate bonds; (iv) Uncovered bonds, ABSs, and non-marketable (“Uncovered etc”); (v) German origin; (vi) PIIGSC origin; and (vii) Own-use.

Finally, we report on a set of variables labeled “excess collateral.” These are defined on a given day  $t$  as

$$Excess\ collateral_t = \frac{Collateral\ value_t - Excluded\ collateral_t - Credit_t}{Collateral\ value_t - Excluded\ collateral_t}, \quad (2)$$

where  $Excluded\ collateral_t$  is the collateral value of an excluded collateral subset, if any. A large excess collateral without exclusions is indicative of low collateral opportunity costs, especially for the collateral types with large portfolio weights. Excess collateral also gauges to what extent German banks may be collateral constrained. By excluding certain subsets of what we may think of as lower quality collateral, the excess collateral variables tell us what the excess collateral value would be if the collateral of the excluded subset were written down to zero or not eligible. We consider three “excluded subsets,” namely: (i) Collateral of non-German origin; (ii) Uncovered, ABS, and non-marketable; (iii) the union of “Uncovered etc” and PIIGSC domiciled collateral. Excess collateral given these exclusions is informative with respect to the strength of the aggregate collateral pool and, by implication, German banks. Overall excess collateral (no subset excluded) is also calculated.

We report on average values of the variables discussed above over the following five sub-periods: (1) “2006.” January 18, 2006 to January 16, 2007. (2) “Pre-Crisis.” January 17, 2007 to August 7, 2007. (3) “Crisis-to-Lehman.” August 8, 2007 to September 9, 2008. Lehman Brothers filed for bankruptcy on September 15, 2007.<sup>21</sup> (4) “Post-Lehman.” September 16, 2008 to January 19, 2010. (5) “2010.” January 20, 2010 to December 31, 2010. Thus, for periods (1)–(3) and the first month of period (4), the liquidity neutral policy applies and haircuts are set according to Table 1, Panel A. For most of period (4) and the whole of period (5), the full allotment policy applies, as do haircuts from Table 1,

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<sup>21</sup>The start date (end date) for each sub-period is chosen to correspond to the beginning (end) of a maintenance period, except (i) sub-period (4), where we begin the period the day after Lehman’s bankruptcy rather than the first day of the relevant maintenance period, September 10, 2008. One weekly Eurosystem aggregate credit data point drops out (but this has no noteworthy effect on the statistics we calculate). The Bundesbank data has no sample days in the period September 10–15, 2008. (ii) The end date in sub-period (5) corresponds to the end of our sample, rather than the end of a maintenance period.

Panel B.

Because the sampling frequency carried out by the Deutsche Bundesbank varies over time, we use the following procedure to average within each sub-period. First, we take the equally weighted average across all sample days within the same maintenance period. We do the same for the weekly aggregate Eurosystem credit figures. Second, we take the equally weighted average across all maintenance periods in each of the five sub-periods. We also do this for the whole sample period.

**Insert Table 2 here.**

Table 2 shows the patterns of the average values for our variables for the full sample period and the five sub periods. Panel A shows that from 2006 to 2010, German registered banks reduce the aggregate liquidity uptake (credit) from EUR 233.0 to 149.6 billion, or by 35.8%. Over the same time period, Eurosystem liquidity injections increase from EUR 424.1 to 653.1 billion. German banks' share of total Eurosystem credit thus drops from 54.94% in 2006 to 22.91% in 2010. Most of this decrease occurs in 2010, coinciding with the maturity of the first ever one-year LTRO (July 1, 2010), where EUR 440 billion fell due. The dramatic decrease is testament to the increasingly fragmented market for liquidity in the euro area. Under the view that German banks suffered less as the crisis progressed than banks in other parts of the euro area, this constitutes a first piece of evidence that worse banks have a relatively larger uptake of liquidity from the central bank.

Panel A also shows that German banks' aggregate collateral pool value vastly exceeds their liquidity uptake. Even in 2006, the aggregate coverage ratio (collateral value to credit) is more than two to one. It has grown over time, reaching 4.47 as an average in 2010. This indicates that there has always been little use for much of the collateral held by German banks outside of Eurosystem operations. It supports the view that the ECB has an accommodative collateral policy, as argued by Nyborg (2016a). This gives rise to the possibility of systemic arbitrage.

The aggregate portfolio weights in Panel B show that collateral quality decreases over time from 2006 to Lehman's bankruptcy, but recovers thereafter. For example, from 2006 to "Lehman," there is a shift of approximately 10 percentage points (pps) from government and covered bonds to "Uncovered etc" collateral. The trend continues but at a much weaker pace into the post Lehman period, but then reverses somewhat, especially for government

bonds, whose weight increases by around 6 pps from “Lehman” to 2010. There are also large shifts taking place with respect to the origin of the collateral used by German banks in repos with the Eurosystem. From 2006 to “Lehman,” German domiciled collateral decreases by around 10 pps, while PIIGSC collateral increases by 6 pps. After Lehman’s bankruptcy and the introduction of full allotment, there is a sharp reversal. German domiciled collateral increases by around 18 pps to 63.04%, while PIIGSC collateral falls around 14 pps to 13.54%. This is consistent with financial fragmentation in the euro area.

These numbers also show that German banks reduce risks in the aftermath of Lehman’s bankruptcy and the introduction of the full allotment policy. This is at odds with claims that there has been widespread increase in risk taking behavior across the euro area over this time period (e.g., Drechsler, Drechsel, Marquez-Ibanez, and Schnabl, 2016).<sup>22</sup>

Panel C shows that, overall, collateral in excess of credit increases from 52.90% in 2006 to 77.95% in 2010. Thus, German banks are not collateral constrained. However, excluding all “Uncovered etc” and “PIIGSC” collateral, the excess collateral is actually negative from 2006 until the post-Lehman period. In the pre-crisis period, it is a whopping  $-28.03\%$ , suggesting that German banks may have been under some pressure up to Lehman’s bankruptcy. This subsequently reversed. In 2010, the excess collateral excluding “Uncovered etc” and “PIIGSC” collateral is at its highest ever level at 45.95%. This supports our conclusion from Panel B that German banks reduced risks as the crisis progressed.

Overall, the aggregate statistics indicate dramatic shifts in Eurosystem liquidity uptake

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<sup>22</sup>Drechsler et al (2016) use a sample of 284 euro area banks and find that banks with worse ratings in 2007 experience a relatively larger decrease in the average rating of their collateral pool holdings and an increase in PIIGS collateral after June 2010, while at the same time also seeing a relative increase in their liquidity uptakes. It is, however, important to note that the sharp relative increase, which the authors show, in total borrowing by weaker banks in July 2010 coincides with the maturity of the first one-year LTRO, where EUR 440 billion fell due. The first Greek bailout, however, started more than one month earlier, in May 2010, for which the authors’ graphs on borrowing show little by way of any effect. This casts doubt on whether the applied methodology (difference-in-difference) identifies relatively higher risk taking by weaker banks as argued by the authors. Potentially, stronger banks in the euro area paid back relatively more when the first one-year LTRO matured while weaker banks rolled over the one-year borrowing. Most plausibly, the authors’ findings reflect increased financial fragmentation in the euro area along PIIGS(C)–non-PIIGS(C) lines. Additionally, the authors claim that differences in the behavior of strong and weak banks only emerged after the onset of the European sovereign debt crisis. We show that this is not the case, they always existed.

and collateral holdings across banks in the euro area as the crisis unfolded. They are consistent with financial fragmentation along national lines and support the view that the full allotment policy buttressed the weaker countries. Below, we exploit heterogeneity within the universe of German banks to study the effects of the full allotment policy (among other things) on weaker and stronger banks' liquidity uptakes and collateral pool holdings.

### 3. Panel data, variables, and descriptive statistics

In this section and in the remainder of the paper, we utilize the panel structure of our data.

#### 3.1 Data

We clean the main data on collateral and liquidity uptake before combining it with additional data on financial health and deposit flows. This is done slightly differently than for the aggregate analysis, since now we are concerned with having complete data for each individual bank. Starting with the 813,576 bank-day observations in the raw data described in Subsection 2.3, we first remove 646 bank-day observations due to missing or zero collateral values. We also drop: 8,129 bank-day observations with negative or missing haircuts;<sup>23</sup> 5,954 additional bank-days with incomplete collateral data; 173 outliers (from five banks) where liquidity uptake exceeds daily reserve requirement by a multiple of more than 1,000; 2,455 observations with negative reserve holdings; 2,684 observations for which either bank type information is missing or the bank's official type changes within the sample period. We also exclude the two consecutive maintenance periods that include Lehman Brothers' bankruptcy and the start of the ECB's full allotment policy. This covers the period September 10–November 11, 2008 and reduces the sample by 8,424 bank-day observations. Finally, we lose 74,049 bank-days because the reserve data ends in October 2010 and is also only available for banks that were required to hold reserves as of that month.

The final collateral and liquidity uptake data consists of 711,062 bank-day observations (87.4% of the raw data). Along the same lines as for the aggregate analysis, for each bank, we average all variables (described below) across sample days within each maintenance period. This leaves us with 55,334 bank-maintenance period observations.

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<sup>23</sup>These observations include the 7,029 bank-day observations without information on the country of origin in Section 2.4.

This bank-maintenance period sample is combined with monthly balance sheet and yearly income statement data for all German registered banks. The balance sheet statistics provide us with the book values of equity and total assets (bank size) and end-of-month deposits from banks and non-banks (that we use to measure deposit flows). From the income statements, we obtain write-offs and provisions as well as return on assets (ROA).

We merge the three datasets by, for each bank-maintenance period, using the monthly balance sheet statistics (yearly income statement statistics) that apply at the end of the month (year) immediately preceding the start of the maintenance period. Deposit data are handled separately as described in the next subsection. In doing this, we drop 1,501 bank-maintenance period observations without information on total assets, book value of equity, write-offs and provisions, ROA, or deposits. The final data on which we will carry out the panel analysis covers 56 maintenance periods and consists of 53,833 bank-maintenance periods involving 1,360 banks.

No banks in the Bausparkassen category survived the data filtering process. As noted by Fecht, Nyborg, and Rocholl (2011), these institutions have reserve requirements that are almost zero and therefore end up as extreme outliers in measures involving reserves. However, the final sample includes banks from all the other eight bank types.

## 3.2 Variables

The variables are divided into five categories; credit (liquidity uptake), collateral quality, financial health, deposit flow, and (collateral) concentration. All variables are per bank per maintenance period, as described above.

Credit (liquidity uptake) is equally weighted across sample days within each maintenance period and normalized by either total assets or daily average required reserves and expressed as a percentage of these. Credit normalized by total assets shows how much of a bank's balance sheet is financed by the ECB. In most of our regressions in Section 4, the variable on the left hand side is a bank's credit normalized by total assets.

The collateral variables are quantity weighted by collateral value across a bank's collateral pool for each sample day and then averaged across each maintenance period. Collateral quality variables are haircut, duration, probability of default (from the Bundesbank's proprietary model), liquidity category, and own-use. The latter is the collateral value of own-use collateral divided by total collateral value in a bank's pool. The concentration of

a bank’s collateral pool is measured by the Herfindahl-Hirschman index based on either asset class or issuer group.

We use the same three financial health variables as Fecht, Nyborg, and Rocholl (2011), namely (i) the equity ratio, defined as the book value of equity divided by total assets (balance sheet, monthly), (ii) write-offs and provisions (income statement, yearly) and (iii) ROA (income statement, yearly).

Deposit flows are based on monthly deposit data from banks’ balance sheets and divided into bank and non-bank flows, both normalized by either assets or reserve requirements. Thus, there are four deposit flow variables in total. We are interested in deposit flows as a control to liquidity uptake and therefore wish to use it for the maintenance period that is contemporaneous to liquidity uptake. However, maintenance periods do not correspond to calendar months. We therefore proceed as follows, using the bank deposit flow normalized by assets as an example.

First, for each bank  $i$  and month  $t$ , define  $\Delta Deposits_{i,t} = Deposits_{i,t} - Deposits_{i,t-1}$ , where *Deposit* refers to bank deposits. Second, for maintenance period  $p$ , define

$$\Delta Deposits_{i,p} = \frac{d_{t-1} \times \Delta Deposits_{i,t-1} + d_t \times \Delta Deposits_{i,t}}{d_{t-1} + d_t},$$

where  $d_s$  is the number of days in month  $s$  that are in maintenance period  $p$ . This gives an estimate of the average daily bank deposit flow in maintenance period  $p$ . Finally, for bank  $i$  in maintenance period  $p$  we define the normalized deposit flow as

$$Normalized\ deposit\ flow_{i,p} = \frac{\Delta Deposits_{i,p}}{Total\ assets_{i,p}}, \quad (3)$$

where  $Total\ assets_{i,p}$  is the total assets the last month before the start of maintenance period  $p$ . When we normalize by reserve requirements, we use the daily average reserve requirement for maintenance period  $p$ . Normalized non-bank deposit flows are defined analogously.

### 3.3 Descriptive statistics

We report descriptive statistics over the total sample period and three sub-periods. We use longer sub-periods than under the aggregate analysis in Subsection 2.4 in order to increase the power of our tests. The sub-periods are: (1) “Pre-crisis.” January 18, 2006 to August 7, 2007. (2) “Early Crisis.” August 8, 2007 to September 9, 2008. (3) “Full Allotment.”

November 12, 2008 to November 9, 2010. The start (end) date of each sub-period always coincides with the start (end) of a maintenance period. The number of maintenance periods in each period are 19, 13, and 24, respectively.

For each sub-period, we first take an equally weighted average across bank-maintenance periods for each bank, leaving us with a population of bank-subperiod observations for which we calculate means etc.<sup>24</sup> The reported statistics thus capture cross-sectional features of the data within each sub-period. For reasons of data confidentiality, we are not allowed to report statistics that are taken from a single observation. Therefore, instead of minimums and maximums, we average the three smallest and three largest observations (for the relevant variable), which we refer to as Min3 and Max3, respectively. For the median we average three (four) observations around the median if the number of observations is odd (even). This variable is referred to as Median34. All references to a minimum, maximum, or median, below, refer to the Min3, Max3, or Median34 statistics, respectively.

**Insert Table 3 here.**

Table 3 provides descriptive statistics of normalized credit, collateral quality, financial health, normalized deposit flow, and collateral concentration for the three sub-periods (Panels A, B, and C) and the full sample period (Panel D). Note first that for normalized credit, the Min3 statistic is zero in all sub-periods. This means that many banks with collateral in their pools do not ask for Eurosystem credit. Focusing on credit normalized by total assets, we see that average liquidity uptake (credit) increases dramatically under full allotment, going from 1.39% and 1.27% over the pre-crisis and early crisis periods, respectively, to 2.60% under full allotment.

As we know from Subsection 2.4, the increase in average liquidity uptake is not due to an aggregate increase by German banks. Thus, it must reflect a large increase in the number of smaller banks that take Eurosystem credit. As seen in Table 3, the number of banks in our dataset increases from 879 and 833 in the pre-crisis and early crisis periods, respectively, to 1,335 under full allotment. Recall that our dataset is comprised of all banks with collateral in their respective eligible collateral accounts with the Bundesbank.

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<sup>24</sup>Note that our basic collateral and liquidity uptake data are provided for all banks with collateral in their respective pools. The averaging for each bank here is therefore across maintenance periods on which a bank has collateral in its pool (on at least one of the sample days).

The largest increase is among cooperatives, from 363 in the early crisis to 774 under full allotment, suggesting that this sector was hit especially strongly by the crisis.

For the average bank in the sample, collateral quality declines under full allotment. Regardless of which measure we look at, the mean is higher under full allotment as compared with the early crisis period. For example, the average liquidity category goes from 2.69 and 2.92 over the pre-crisis and early crisis periods, respectively, to 3.35, under full allotment. The corresponding figures for haircuts are 2.22%, 2.70%, and 5.89%, reflecting, in part, the ability of banks to use lower rated collateral under full allotment. The average probability of default increases from 3.10 bps to 3.76 bps as we go from the early crisis to full allotment, but was a surprisingly large 6.66 bps over the pre-crisis period. Default probabilities are measured over the next twelve months by the Bundesbank's proprietary model. We do not have access to the details of this model, but our understanding is that it may have been updated from time to time. In the regression analysis, we use maintenance period fixed effects to control for potential changes over time and, for robustness, several measures of collateral quality.

The average bank's financial health is relatively stable over time. The average equity ratio is 5.56%, 5.58%, and 5.56% for the pre-crisis, early-crisis, and full allotment periods, respectively, with the corresponding numbers for write-offs and provisions being 0.53%, 0.49%, and 0.45%. However, there is substantial variation across banks. For example, under full allotment, write-offs and provisions range from 0.00 to 2.76%. Not surprisingly, ROA falls as the crisis evolves, with the averages being 0.18%, 0.15%, and 0.05% over the three sub-periods in chronological order.

For deposit flows, it is arguably most interesting to focus on the variation across banks. This increased over time, especially for interbank flows. In the pre-crisis period, the standard deviation of this measure across banks is 0.51%, increasing to 0.77% and 2.13% for the early crisis and full allotment periods, respectively. This is consistent with the idea that markets, even within Germany, became more segmented. The large increase in the number of banks in our dataset in the full allotment period may also reflect such segmentation.

Mean values for the two Herfindahl-Hirschman indexes show that individual banks' holdings of collateral are fairly concentrated within specific asset classes. For either the asset class or issuer group measures, there are eight individual categories (see footnote 18). An even spread of collateral (by collateral value) across the eight categories would give

an HHI value of 12.5%. Over the three sub-periods, mean values range from 63.73% to 65.77% (asset class) and 79.61% to 85.53% (issuer group). So the average bank essentially holds collateral within one to two categories. Over the whole sample period, the correlation between the two measures is 0.62.

**Insert Table 4 here.**

Table 4 complements Table 3 by providing average values, within each sub-period, for our variables for five size-sorted groups. The five groups comprise the four quartiles of the size distribution, with the last quartile being divided into banks in the 99th percentile (14 banks) and the rest. The size groups are constructed according banks' average sizes over the full sample period.

The table reveals that larger banks took more Eurosystem credit, relative to their total assets, than smaller banks before the introduction of full allotment. For example, for the 14 largest banks, the average liquidity uptake is 3.17% and 2.57% of total assets in the pre-crisis and early crisis periods, respectively. For the smallest quartile of banks, the corresponding numbers are 0.59% and 0.48%. After the introduction of full allotment, however, this reverses. For the 14 largest banks, the average liquidity uptake is now 1.61% of total assets as compared with 2.42% for the smallest quartile. While this suggests a reversal of fortune for large and small banks, this is not so evident when looking at the collateral quality variables. For example, haircuts increase slightly more for the largest group than for the smallest. Next, we turn to examining the relation between liquidity uptake, size, collateral quality, and other variables more carefully using panel regressions.

## 4. Panel regressions: Liquidity uptake

This section studies the relation between liquidity uptake, collateral quality, financial health, deposit flows, and collateral concentration. We run panel regressions using the bank-maintenance period structure of the data described in Section 3. Our focus is especially on the determinants of liquidity uptake at the individual bank level.

In the first subsection, we use haircuts as a measure of collateral quality. Maintenance period fixed effects control for the inclusion of collateral rated in the BBB+ to BBB- range in October 2008, with associated larger haircuts. In the second subsection, we decompose

haircuts into liquidity category, duration, and probability of default. In the third and last subsection, we then repeat the initial regression with the full set of collateral quality variables as well as the unexplained portion of haircuts from the exercise in the second subsection.

## 4.1 Regressions using haircuts to capture collateral quality

We regress liquidity uptake, or credit, normalized by total assets on size  $[\ln(\text{assets})]$ , haircuts, the three financial health variables, bank and non-bank deposit flows normalized by total assets, and collateral concentration, with bank type and maintenance period fixed effects. A squared term is included for the equity ratio to account for nonlinear effects from this variable. Collateral concentration is captured by the HHI over issuer groups.<sup>25</sup> All financial health variables are lagged (as discussed in Section 3). Because credit is truncated at zero, we use the tobit procedure.<sup>26</sup> Separate regressions are run for the pre-crisis, early crisis, and full allotment periods as described in Section 3 as well as for the full sample period.

The results are in Table 5. Panel A reports the tobit coefficients, with  $t$ -statistics based on standard errors clustered at the individual bank level in parentheses underneath. Statistical significance (two-tailed) at the 1%, 5%, and 10% levels are indicated by *a*, *b*, and *c*, respectively. We have also calculated standard errors using the Huber-White correction for heteroskedasticity and report the level of significance of the tobit coefficients based on these standard errors in square brackets, using the same lettering scheme.

Tobit coefficients are difficult to interpret economically as they represent a combined measure of, in our case, (i) the change in the probability of taking credit (PoC), and (ii) the change in normalized credit conditional on taking credit (CCoC).<sup>27</sup> To help gauge the economic significance of the results, in Panel B of Table 5, we decompose the tobit coefficients into the effects of a one unit change in the independent variable on PoC and CCoC. For each independent variable, we report the average of each of these two marginal

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<sup>25</sup>The high correlation between HHI(issuer group) and HHI(collateral class) precludes us from including both measures. There are no noteworthy differences from using one or the other measure. Details are available from the authors upon request.

<sup>26</sup>We have also run the panel regressions without the tobit procedure and using credit normalized by reserve requirements, with similar results. Details are available from the authors upon request.

<sup>27</sup>See McDonald and Moffitt (1980).

effects, keeping the other independent variables fixed at observed values.  $z$ -statistics with standard errors clustered at the individual bank level are in parentheses underneath the average marginal effects. Significance levels using clustered and Huber-White standard errors are indicated in the same way as in Panel A.

**Insert Table 5 here.**

With respect to the tobit coefficients in Panel A, we start by noting that normalized credit is increasing in bank size. The coefficients are statistically significantly different from zero at the 1% level for all sub-periods, using either type of standard error, except under full allotment with standard errors clustered at the bank level, where the coefficient is not statistically significant. This echoes the results from the size-sorted descriptive statistics in Table 4. However, the regression results show that the relatively small liquidity uptake by large banks under full allotment may reflect other characteristics of these banks.

Importantly, with respect to the hypothesis of systemic arbitrage, we see first that higher haircuts, i.e., lower collateral quality, are associated with larger liquidity uptakes. The haircut coefficient is statistically significant at the 1% level in all sub-period regressions, regardless of how we calculate standard errors. With respect to economic significance, Panel B shows that in the pre-crisis period, a one percentage point increase in haircut increases the probability of taking credit by 2.5 percentage points and, conditional on a bank taking credit, increases normalized credit by 0.148 percentage points. The latter effect represents a 10.69% increase over the average normalized credit, which is 1.39% in the pre-crisis period. Both marginal effects are about twice as large in the pre-crisis period as compared to the early-crisis and full-allotment periods.

With respect to the effect of financial health, the results on the equity ratio show that firms with relatively more healthy equity positions have lower liquidity uptakes. In the specification with Huber-White standard errors, the coefficients are negative and statistically significant at the 1% level in every sub-period. Using clustered standard errors, the coefficients remain significant for the pre-crisis and full allotment periods, at the 10% and 1% levels, respectively. Thus the results on the equity ratio are especially strong under full allotment. This supports the view that funding, and not only mere liquidity, is provided to banks through Eurosystem repos under the full-allotment policy.

To account for the possibility of a nonlinear relation between the equity ratio and

liquidity uptake, we have also included a square term (of equity ratio). This is positive and statistically significant at least at the 5% level in all sub-periods, using either type of standard error. This indicates that the relation between the equity ratio and normalized credit is downward sloping and convex, which makes intuitive sense.

Economically (Panel B), the effects of the equity ratio on liquidity uptake are similar in the pre-crisis and the full-allotment period, but weaker in the early-crisis period. In the full-allotment period, for instance, a one percentage point decrease in equity ratio increases the probability of positive credit by 2.4 percentage points and, conditional on a bank taking credit, increases credit as of total assets by 0.147 percentage points. The latter represents a 5.65% increase over the average normalized credit in the full-allotment period.

The coefficients on write-offs and provisions are also statistically significant in all sub-periods. In the clustered standard errors specification, the p-value is at least 10% across all sub-periods. This is quite remarkable given that this variable is measured with yearly frequency. However, the coefficient changes from negative in the two pre-full allotment sub-periods to positive under full allotment. While the full allotment result is consistent with systemic arbitrage taking place, the negative coefficients in the two earlier sub-periods are surprising. This may be a result of relatively weaker banks understating, or “hiding”, losses before the worst onslaught of the crisis. Such behavior could explain why the results are weaker for the equity ratio in the early-crisis period as well. As the crisis progressed, hiding losses may have become increasingly difficult to do.

Economically (Panel B), in the full-allotment period, a one percentage point increase in write-offs and provisions (as a percentage of total assets) increases the probability of positive credit by 6.8 percentage points and, conditional on a bank taking credit, increases normalized credit by 0.405 percentage points. The latter represents a 15.58% increase over the average normalized credit in the full-allotment period.

Table 5 also uses the two deposit flow variables as controls. These measures are important as they capture the extent of deposit inflows that a bank receives from private markets, which in turn determine its need for more credit from the Eurosystem. Furthermore, banks perceived as being better than others might experience a significant deposit inflow and thus having a relatively lower need for getting liquidity directly from the central bank. In contrast, banks perceived as being worse might be exposed to deposit outflows and are thus in need of central bank money. The results on deposit flow are interesting.

An increase in deposit flows from non-banks is associated with a decrease in Eurosystem credit in both the pre-crisis and early crisis periods. Bank-deposit flows have the opposite effect. Thus, while non-bank deposits appear to be a substitute for Eurosystem credit, bank deposits are complements. The effect of either kind of deposit disappears after the onset of the full allotment policy. In other words, the central bank policy of full allotment has almost obliterated the role of markets with respect to banks' liquidity management.

The coefficient on the Herfindahl-Hirschman index is negative and statistically significant at the 1% level, using either type of standard error, in all sub-periods. This shows that banks that take more credit from the Eurosystem have a broader set of collateral holdings. It may well be that taking more credit requires acquiring a broader set of eligible collateral. What is interesting here is that while one might expect this to be increasingly better collateral with higher opportunity costs, the positive coefficients on haircut suggests that banks are able to broaden their collateral holdings into worse, rather than better, collateral when they seek more liquidity from the Eurosystem. This is supportive of the systemic arbitrage hypothesis.

To summarize, the results point to the existence of systemic arbitrage whereby banks in worse financial health and with worse collateral have larger liquidity uptakes from the central bank. The results are slightly stronger under the full-allotment period, when alternative sources of liquidity may have been reduced for many banks. Controlling for an unobserved bank effect by clustering at the bank level weakens the results only slightly relative to using Huber-White standard errors; the main variables remain statistically significant at conventional levels. This provides an illustration of the strength of the results, especially given the low frequency occurrence of the financial health variables and their relative lack of variation. That there are only relatively small differences, in terms of inferred statistical significance, between using Huber-White and clustered standard errors also suggests that our regression model is reasonably well-specified (Petersen, 2009; King and Roberts, 2015).

## 4.2 Haircuts and other collateral quality measures

Our use of Eurosystem haircuts as a rough and ready measure for collateral quality is based on Table 1, which shows that haircuts are increasing in duration, default probabilities (as captured by the rating), and illiquidity (as captured by the Eurosystem's liquidity category

classification). In this subsection, we take a closer look at the extent to which these variables explain haircuts by using our bank-maintenance period panel data to regress haircuts on these more specific collateral quality measures. The findings are in Table 6.

**Insert Table 6 here.**

Panel A provides correlations of the three collateral quality measures over the three sub-periods discussed above and over the full sample periods. The correlation coefficients range from -0.273 (duration and default probability, pre-crisis) to 0.527 (liquidity category and default probability, full allotment), showing that the three variables capture different properties of banks' collateral pools.

Panel B contains the regressions. Over the three sub-periods, the adjusted  $R^2$  ranges from 0.236 (early crisis) to 0.673 (full allotment period), showing that haircuts are fairly well explained by the three specific collateral quality measures. The coefficients on all three measures are statistically significant at the 1% level in all four regressions. This is not surprising given how Eurosystem haircuts are set, as seen in Table 1. As expected, haircuts are seen to increase in duration, liquidity category, and default probabilities. This holds true in all sub-periods, with one exception, namely the coefficient on the probability of default is negative in the pre-crisis period. This is odd, especially because the probability of default is calculated from the Bundesbank's own model. Overall, the results in Table 6, Panel B support the view that haircuts capture collateral quality, but also that our three specific collateral quality measures do not explain haircuts completely. This may be a result of the haircuts being updated infrequently and the relatively coarse grid that is used to set them, as seen in Table 1. Thus, it is interesting to revisit the regressions in the previous subsection with haircuts broken out into its "components."

### 4.3 Regressions using all collateral quality measures

In this subsection, we run tobit regressions that are essentially the same as those in Table 5, except that haircuts are replaced by its components; duration, probability of default, liquidity category, and the residual from regressing haircuts on these specific collateral quality measures.<sup>28</sup> We also include collateral own-use, which measures the fraction of collateral issued by an entity with which the bank that holds the collateral has close links. This can

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<sup>28</sup>The residuals are from cross-sectional regressions within each maintenance period.

be viewed as a fourth collateral quality measure in that it may represent collateral that banks were unable to place in the market.

**Insert Table 7 here.**

The results are in Table 7. The structure is the same as for Table 5. Panel A reports on the tobit coefficients and Panel B on the marginal effects. Our discussion concentrates on the collateral quality variables. The results are essentially the same as in Table 5 for the financial health, deposit flow, and HHI variables.

We see in Panel A that liquidity uptake is increasing in the liquidity category and the probability of default in all three sub-periods, with all coefficients being statistically significant at least at the 5% level when using clustered standard errors. This supports our conclusion in Subsection 4.1 that banks with lower quality collateral take more Eurosystem credit.

The results on duration are in line with this conclusion for the pre-crisis and early-crisis periods, with the pre-crisis (early-crisis) coefficient being positive and statistically significant at the 1% level when using clustered (Huber-White) standard errors. However, under full allotment, the coefficient on duration changes sign, becoming significantly negative. This may reflect the composition of banks' collateral pools. Table 6 shows that duration is negatively correlated with both the liquidity category (except over the early crisis period) and the probability of default. Thus, it is possible that the negative coefficient on duration in Table 7 under full allotment reflects a dominant usage of relatively short term, but risky and illiquid collateral among some German banks.

The coefficient on own-use is statistically significant (using either type of standard error) only in the full allotment period, when it is positive. This is suggestive of a particularly active exploitation of the correlated default loophole in the collateral framework during the full allotment period. Work not shown here indicates that this is especially driven by private loan banks and special purpose banks.

With respect to economic significance, Panel B shows that, in the pre-crisis period, a one-step increase in the liquidity category increases the probability of positive credit by 13.7 percentage points. Conditional on a bank taking credit, it also increases normalized credit by 0.813 percentage points, which is 58.61% larger than the average normalized credit in the pre-crisis period. PoC is approximately 60% larger in the pre-crisis period than the

early crisis and full-allotment periods, and CCoC is almost twice as large. In contrast, for the probability of default, both marginal effects are much smaller for the pre-crisis period than the other two periods. Under full allotment, a one basis point increase in the probability of default increases the probability of positive credit by 1.1 percentage points and, conditional on a bank taking credit, increases normalized credit by 0.065 percentage points. The latter represents a 2.52% increase over the average normalized credit in the full allotment period.

Panel B also shows that in the pre-crisis (full allotment) period, a one year increase in duration increases (decreases) the probability of positive credit by 2.5 (1.6) percentage points and, conditional on positive credit, increases (decreases) normalized credit by 0.150 (0.096) percentage points. The latter represents a 10.80% (3.70%) increase (decrease) over the average normalized credit in the pre-crisis (full allotment) period.

Finally, in the full allotment period, a one percentage point increase in own-use as a percentage of total assets increases the probability of positive credit by 0.4 percentage points and, conditional on positive credit, increases credit as of total assets by 0.022 percentage points. The latter represents a 0.85% increase over the average normalized credit in the full allotment period.

To summarize, the results in this section support the view that banks take advantage of the Eurosystem's collateral framework. In particular, banks in worse financial health and with worse collateral have larger liquidity uptakes relative to their assets than financially healthier banks with better quality collateral. In short, banks engage in systemic arbitrage. It is noteworthy that this describes the data over all three sub-periods, including the pre-crisis period. Thus, systemic arbitrage is not a crisis phenomenon, but reflects more fundamental issues with the Eurosystem's collateral framework.

## 5. Panel regressions: Collateral quality

We have seen that banks with worse collateral and in worse financial health have relatively large liquidity uptakes. In this section, we ask whether it is also the case that banks in worse financial health have worse collateral. This is an interesting question, in part, because it would imply an amplification of systemic arbitrage. It also relates to the idea, discussed in the Introduction, that banks have an incentive to pledge collateral that is relatively

more likely to default when the bank itself defaults (“correlated collateral”). This is so because haircuts are not adjusted for “plain” counterparty risk or the risk of joint default of collateral and counterparty. While the granularity of the data does not allow us to test specifically whether weak banks have especially large usage of correlated collateral, we can test whether they have relatively larger usage of low quality collateral.

In this section, therefore, we regress measures of collateral quality on financial health. As before, collateral quality is captured by the haircut and its three “components,” probability of default, liquidity category, and duration. We use the same bank-maintenance period data as described in Sections 3 and 4. As above, we run panel regressions with bank sector and maintenance period fixed effects. In our main specification, standard errors are clustered at the bank level, but we also report significance levels based on Huber-White corrected standard errors.

Because we are primarily interested in the relation between collateral quality and financial health for bank-maintenance period observations with positive liquidity uptake, we use the Heckman selection model.<sup>29</sup> This combines a selection mechanism for having a positive liquidity uptake with a panel regression of collateral quality on the three financial health variables (equity ratio, write-offs and provisions, ROA) and the fixed effects. Indexing banks by  $i$  and maintenance periods by  $j$ , the selection equation is

$$z_{ij}^* = \gamma' w_{ij} + \mu_{ij}. \quad (4)$$

The regression model is

$$y_{ij} = \beta' x_{ij} + \epsilon_{ij}, \quad (5)$$

where  $(\mu_{ij}, \epsilon_{ij})$  are assumed to be bivariate normal  $[0, 0, 1, \sigma_\epsilon, \rho]$ .

$z_{ij}^*$  is not observed; the variable is observed as  $z_{ij} = 1$  if  $z_{ij}^* > 0$  and 0 otherwise with probabilities  $\text{Prob}(z_{ij} = 1) = \Phi(\gamma' w_{ij})$  and  $\text{Prob}(z_{ij} = 0) = 1 - \Phi(\gamma' w_{ij})$ .  $z_i = 1$  indicates that the bank has positive liquidity uptake (takes credit) and  $\Phi$  is the standardized normal cumulative distribution function.

In the selected sample,

$$E[y_{ij}|z_{ij} = 1] = \beta' x_{ij} + \rho\sigma_\epsilon\lambda(\gamma' w_{ij}), \quad (6)$$

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<sup>29</sup>In work not reported here, we have also run plain panel regressions. The results turn out to be very similar.

where  $\lambda$  is the inverse Mills ratio. The model is estimated by maximum likelihood, see Greene (2000), which provides consistent, asymptotically efficient parameter estimates.

The selection equation includes an additional variable, that is not in the regression model, namely Positive liquidity uptake $_{i,j-1}$ .<sup>30</sup> This is an indicator variable that is 1 if bank  $i$  has positive credit from the Eurosystem in maintenance period  $j - 1$  and zero otherwise. As before, we run the model over the full sample period and over each of the three sub-periods; pre-crisis, early crisis, and full allotment. The results are in Table 8.<sup>31</sup>

**Insert Table 8 here.**

The findings in Table 8 are broadly consistent with the hypothesis that banks in worse financial health use worse collateral, but with a lower degree of statistical significance than in the previous section. Our discussion starts with the case that the haircut is the dependent variable (Panel A) and then moves on to the cases where probability of default (Panel B), liquidity category (Panel C), and duration (Panel D) are the dependent variables.

As seen in Panel A, the coefficient on the equity ratio is consistently negative across all sub-periods, indicating that banks with a lower equity ratio use collateral with higher haircuts. The coefficients are statistically significant at the 1% level in all sub-periods using Huber-White standard errors. Using clustered standard errors, only the pre-crisis period coefficient is statistically significant at conventional levels (5%). In terms of economic magnitude, a one standard deviation decrease in the equity ratio increases the haircut by 0.11, 0.04, and 0.04 standard deviations in the pre-crisis, early crisis, and full allotment periods, respectively.<sup>32</sup>

The coefficients on write-offs and provisions are positive for all sub-periods, which is consistent with banks in worse financial health employing worse collateral. Based on Huber-White standard errors, the coefficients are statistically significant at the 1% level in the pre-crisis and full allotment periods. Using bank-clustered standard errors, we have statistical significance at conventional levels only in the pre-crisis period, but the p-value is 12.2% in the full allotment period. These are relatively strong results given the lack of variation in

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<sup>30</sup>We have also used the two deposit flow variables in the selection equation, without this making a noteworthy qualitative difference to the results.

<sup>31</sup>Because of the additional variable in the selection equation, we lose two maintenance periods in the main regressions (as seen by a comparison between Tables 5 and 8).

<sup>32</sup>Using the standard deviations in the pooled bank-maintenance period sample used in the regressions.

write-offs and provisions due to the infrequent sampling frequency. In terms of economic magnitude, a one standard deviation increase in write-offs and provisions is associated with a 0.17 and 0.03 standard deviation increase in the haircut in the pre-crisis and full allotment periods, respectively. The results on ROA are weaker, as they were in Section 4.

The results in Panel B, where collateral quality is captured by the probability of default, complement those in Panel A. Using bank-clustered standard errors, the coefficient on the equity ratio is negative and statistically significant at the 5% level or better in both the pre-crisis and early crisis regressions. The coefficient on write-offs and provisions is statistically significantly positive at the 5% level in the full-allotment period. We also find that the coefficient on ROA is statistically significantly positive in the early-crisis period, which is somewhat surprising. This may reflect that banks with high ROA take more risk or generally use their assets more efficiently. In terms of economic significance, in the early-crisis (full-allotment) period, a one standard deviation increase in the equity ratio (write-offs and provisions) is associated with a 0.06 (0.07) standard deviation decrease (increase) in the probability of default.

The results using liquidity category and duration (Panels C and D, respectively) also support the view that financially weaker banks use lower quality collateral in central bank repos. Focusing on regressions with statistically significant coefficients based on bank-clustered standard errors, we see that a lower equity ratio is associated with less liquid collateral (pre-crisis and full allotment) and higher duration (early crisis). In addition, an increase in ROA is associated with more liquid collateral (pre-crisis) and lower duration (pre- and early- crisis).

Overall, these findings support the idea that weaker banks use worse collateral, as captured by either the probability of default, liquidity category, or duration. It is noteworthy that the results are strong over the pre-crisis period. This gives credence to our claim that systemic arbitrage is not a crisis phenomenon and leaves us with the important question as to whether systemic arbitrage may have contributed to the severity of the crisis in the first place.

## 6. Discussion: Market discipline impairment and financial fragmentation

Systemic arbitrage is a concern not only because it may weaken the central bank's balance sheet, but also because it may impair the efficiency of the market for liquidity and thereby undermine financial stability. In this section we also raise the issue that it may have contributed to financial fragmentation in the euro area.

Systemic arbitrage channels an overweight of liquidity directly from the central bank to relatively weaker banks. This may affect markets in several ways. First, it reduces the market's disciplinary function with respect to weaker banks since they have less of need to access the secondary market for liquidity. Among other things, this would be expected to reduce information production on the quality of weaker banks' balance sheets. Second, the distribution of credit spreads may widen across banks. The reason is that weaker banks' balance sheets will be relatively highly encumbered, because of their relatively large collateralized liabilities in favor of the central bank; while the opposite is true for relatively strong banks. As a result, the range of expected losses given default on unsecured bank loans widens across banks. In turn, this may reduce the efficiency of the interbank market, for example for reasons articulated in Afonso, Kovner, and Schoar (2011). This is especially relevant if wider credit spreads are accompanied by a rise in information asymmetries, as seems plausible. Third, systemic arbitrage may be associated with an underlying incentive within the banking sector to make weak banks weaker and strong banks stronger. This derives from what we referred to in the Introduction as the credit risk, or correlated default, loophole. In particular, since Eurosystem haircuts are neither adjusted for individual banks' credit risk, nor for the correlations between collateral and bank default risk, banks have an incentive to pledge collateral that is likely to default when they default themselves. The weaker are the banks that obtain the majority of the liquidity from the Eurosystem, and the worse their collateral is, the greater are the arbitrage gains vis-à-vis the central bank.<sup>33</sup>

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<sup>33</sup>This effect is somewhat related to Diamond and Rajan (2011). These authors emphasize the incentives of highly leveraged banks to take correlated liquidity risks, i.e. invest in assets that are especially illiquid conditional on banks experiencing a (severe) liquidity shock. They go on to argue that a sufficient state-contingent liquidity provisioning by the central bank can eliminate, or reduce, the associated inefficiencies. In contrast, the correlated default loophole we emphasize in this paper relates to banks shifting risks by

In short, systemic arbitrage weakens market discipline, reduces information aggregation, and fosters heterogeneity across banks with respect to credit risk and collateral quality. All these factors impair the workings of the market for liquidity and make it more vulnerable to shocks.

These issues may be relevant with respect to the well-documented and severe stress that emerged in the market for liquidity around the time of Lehman Brother's default in the fall of 2008 (see, e.g., Cassola, Holthausen, and Lo Duca, 2010, and Gabrieli and Georg, 2014). Several authors have suggested that information asymmetries about credit risk were at the heart of the problem and have developed theoretical models and/or empirical evidence along those lines (see, e.g., Heider, Hoerova, and Holthausen, 2015, and Bräuning and Fecht 2016).<sup>34</sup> Our suggestion is that systemic arbitrage may have contributed to a growth in both information asymmetries and bank heterogeneity prior to Lehman's default, thereby making the market for liquidity ripe for turmoil. As documented in Sections 4 and 5, systemic arbitrage was also a feature of the market for liquidity before the onset of the crisis. Thus, the markets may have been especially vulnerable to a severe shock, such as the Lehman default in September 2008, coming as it did after more than a year of impairment in the market for liquidity.<sup>35</sup>

Because it increases the scope for systemic arbitrage, the full allotment policy, introduced to alleviate the stress in the markets, may have contributed to worsening conditions over time instead. Our finding in Section 4 that bank and non-bank deposit flows no longer affect banks' liquidity uptakes under full allotment speaks to this, since it means that the role of markets have been greatly reduced under the full allotment policy.

The full allotment policy and the ability to use illiquid collateral in Eurosystem operations may also have reduced incentives for the private provisioning of liquidity for the simple reason that it reduces banks' need to hold liquid assets. Thus, this policy may have

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seeking a strong correlation between their own default and that of the collateral they pledge in central bank repos. The central bank's liquidity support may foster this. Our emphasis is on the incentives created by the micro-design of the central bank's liquidity provisioning.

<sup>34</sup>Freixas and Jorge (2008) also study the effects of information asymmetries and opacity in interbank markets.

<sup>35</sup>We also know that sovereign bond spreads (over German bonds) in the euro area started to increase in the second quarter of 2008 (see, e.g., Nyborg, 2016a), suggesting a shortage of riskfree collateral was developing. This may have reduced the ability of the repo markets to pick up the slack from a stressed unsecured market (apply Ewerhart and Tapking's, 2008, logic).

exacerbated the free-rider problem with respect to the private provisioning of liquidity (Bhattacharya and Gale, 1987). Indeed, Farhi and Tirole (2012) argue that an accommodative monetary policy and expectations of central bank interventions may lead banks to coordinate on excessive liquidity risk taking.

Systemic arbitrage and the correlated default loophole may also have contributed to financial fragmentation in the euro area. Acharya and Steffen (2015, Table 2) document that banks in non-PIIGS eurozone countries decreased their holdings of PIIGS sovereign bonds from March 2010 to June 2012, while banks in PIIGS countries increased theirs. The predicament of eurozone financial fragmentation is discussed in further detail in European Central Bank (2012 and 2014), Van Rixtel and Gasperini (2013), and Cline (2014). Our finding that German banks have decreased their reliance on periphery collateral over time also speaks to rising fragmentation in the euro area. The logic as to how the correlated default loophole in the Eurosystem's collateral framework contributes to a build-up in market fragmentation is straightforward. Under the view that a government default leads to same-country bank defaults, the correlated default loophole implies that banks prize domestic paper because they benefit from a premium paid in the market for a risk that is irrelevant to them. Thus, as sovereigns get weaker, fragmentation is likely to increase.

Fragmentation is also visible in the liquidity uptake data. The evidence in this paper shows that German banks reduced their liquidity uptake, both in absolute and relative terms, under the full allotment policy. We also know that it is especially banks in the periphery member states that have had large liquidity uptakes since the introduction of full allotment (see, e.g., Pisani-Ferry and Wolff, 2012, and Nyborg, 2016a). Thus, our evidence on systemic arbitrage from individual German banks may represent a microcosm of what appears to be a broad trend in the euro area under the period of this study, with weaker banks (from more financially fragile nations) taking increasingly more Eurosystem credit with increasingly lower quality and more correlated collateral. A lack of eurozone market integration hinders the flow of liquidity and capital and undermines the attractiveness of the single currency.

Our argument here is that ECB collateral policy has contributed to financial fragmentation in the euro area, strengthening the unfortunate nexus between sovereigns and banks. The full allotment policy, under the current collateral framework, amplifies fragmentation because it increases the scope for taking advantage of the credit risk and correlated default

loopholes in haircut policy. At the same time, the larger exposure of periphery banks to domestic risky sovereign debt reduces other banks' willingness to lend to them, contributing further to market fragmentation. That the euro interbank market started to fragment well before the euro area sovereign debt crisis brought doubts about the viability of the single currency (Abbassi, Bräuning, Fecht, and Peydró, 2014), supports this view.

Large-scale systemic arbitrage may reduce a central bank's room to maneuver, because it weakens the central bank's own balance sheet and it impairs monetary policy transmission mechanisms that work through interbank markets. In turn, this may lead to a spiral of ever-stronger central bank policies. As systemic arbitrage and fragmentation increases in the euro area, potential losses from the default of crisis countries and their banks mount. As a result, the ECB may see it as necessary to administer increasingly more powerful medicine to keep weaker and highly indebted member states and their banks from defaulting. The ECB's announcement in September 2014 that it will purchase upwards of EUR 1 trillion worth of asset-backed securities, covered bonds, sovereign bonds (added to the program in January 2015), and corporate bonds (added in March 2016), may be seen in this light (Nyborg, 2016a). The euro area's financial system may thus be increasingly vulnerable because it rests increasingly on the Eurosystem's ability to soak up ever larger quantities of lower quality collateral. In short, consistent with Nyborg (2016a), our analysis suggests that the way banks react to central bank policies may negatively affect central bank exposures and, in Klaas Knot's words, ultimately undermine central bank credibility. Given the importance attached to central banks these days, a loss of central bank credibility would likely have serious financial, economic, and political consequences.

## 7. Concluding remarks

In this paper, we study banks' behavior vis-à-vis the central bank in the context of the provisioning of central bank liquidity, i.e., the money creation process. Our analysis makes use of a unique panel data of all German banks' liquidity uptake and pledged collateral in Eurosystem repos from 2006 to 2010. The dataset is comprehensive in that it covers all German banks and all liquidity they obtain directly from the central bank. Because the terms of exchange between central bank liquidity and collateral is determined by the central bank's collateral policy (Nyborg, 2016a), our data allows for an assessment of the workings

of collateral policy in the euro area. The time period covered by the dataset means that we can examine whether banks changed their behavior after the onset of the financial crisis in August 2007 and the introduction of the full allotment policy in October 2008. This is especially important and interesting, in part, because the full allotment policy coincides with a softening of collateral eligibility rules (Eberl and Weber, 2014; Nyborg, 2015 and 2016a).

We first document that, on aggregate, German banks reduce their borrowings from the Eurosystem after the Lehman failure and the introduction of the full allotment policy, both in absolute terms and relative to other euro area banks. While the quality of eligible collateral held by German banks with the Eurosystem declines until Lehman's default, from October 2008 onwards German banks increase their overall collateral holdings relative to their Eurosystem liquidity uptake and improve the average quality of their pledged collateral.

Despite these aggregate developments, our panel analysis at the individual bank level provides evidence of systemic arbitrage by German banks both before and after the onset of the financial crisis. That is, weaker banks generally use lower quality collateral to borrow disproportionately more from the Eurosystem than stronger banks. It is noteworthy that this is not unique to the crisis. It points to a fundamental problem with respect to Eurosystem collateral policy that may well have contributed to the depth of the crisis.

In Eurosystem repos, solvent banks are obliged to provide additional collateral in case the collateral value of their pledged assets falls short of their outstanding credit. Therefore, the Eurosystem's exposure is confined to the risk that a bank fails while at the same time the pledged collateral does not cover the outstanding credit. Systemic arbitrage increases this risk, worsening the Eurosystem's balance sheet and putting taxpayers' money at risk. Systemic arbitrage also undermines interbank market-discipline, distorts competition in the banking sector, and may aggravate tensions in money markets. In short, a collateral policy that allows for systemic arbitrage may contribute to financial instability. Systemic arbitrage may also have contributed to financial fragmentation in the euro area.

Systemic arbitrage could be prevented if the correlation risk – the risk that a bank defaults while its pledged collateral fails to cover the outstanding credits – is correctly reflected in the rates at which a bank obtains credit from the Eurosystem. This may be difficult under today's system, with thousands of eligible counterparties in Eurosystem

operations and a very wide range of eligible collateral. In practice, mitigating systemic arbitrage requires limiting this combination of large sets of eligible banks and lower quality eligible collateral. Thus, it may be worthwhile to consider implementing a primary dealer system, where only prime banks can borrow directly from the Eurosystem, or confining the list of eligible collateral to assets of the highest quality.<sup>36</sup>

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<sup>36</sup>Nyborg, 2016a and 2016b, also discusses ways to inject more market discipline into the collateral framework.

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**Table 1**  
Eurosystem haircuts.

Eurosystem haircuts (in %) for marketable collateral by liquidity category, residual maturity, and coupon (zero, fixed, or floating). Panel A: Applies from March 8, 2004 to December 31, 2006 for tier one marketable assets and, after the introduction of the “single list,” for all marketable assets from January 1, 2007 to October 24, 2008. See Guideline of the European Central Bank (2003) for initial documentation of these haircuts and Guideline of the European Central Bank (2006) for the introduction of the single list. Panel B: Incorporates updates announced on October 23, 2008. Updates in blue slanted type and with a dagger (†) apply from October 25, 2008 (European Central Bank, 2008a). Those in red italic and starred (\*) apply from February 1, 2009 (European Central Bank, 2008b). Nyborg (2016a) provides a further list of references showing the validity of the haircuts in both panels over the full periods listed here. Note that some marketable asset special cases as well as non-marketable assets are not covered by the table. See Nyborg (2016a) for details.

*Panel A: Haircuts applied to marketable tier one assets (from March 8, 2004 to December 31, 2006) or all marketable assets (January 1, 2007 to October 24, 2008)*

		<i>Liquidity categories</i>									
		<i>Category I</i>		<i>Category II</i>		<i>Category III</i>		<i>Category IV</i>			
		Central government debt instruments, Debt instruments issued by central banks		Local and regional government debt instruments, Jumbo Pfandbrief-style debt instruments, Agency debt instruments, Supranational debt instruments		Traditional Pfandbrief-style debt instruments, Credit institution debt instruments, Debt instruments issued by corporate and other issuers		Asset-backed securities			
		Residual maturity (years)	fixed coupon	zero coupon	fixed coupon	zero coupon	fixed coupon	zero coupon	fixed coupon	zero coupon	
		0-1	0.5	0.5	1.0	1.0	1.5	1.5	2.0	2.0	
		1-3	1.5	1.5	2.5	2.5	3.0	3.0	3.5	3.5	
		3-5	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
		5-7	3.0	3.5	4.5	5.0	5.5	6.0	6.5	7.0	
		7-10	4.0	4.5	5.5	6.5	6.5	8.0	8.0	10.0	
		>10	5.5	8.5	7.5	12	9.0	15.0	12.0	18.0	
<b><i>Tier one floating rate debt instruments:</i></b> Same as zero-to-one-year maturity bucket of fixed coupon instruments given the liquidity category.											
<b><i>Tier one inverse floating rate debt instruments:</i></b> Haircuts are the same for all liquidity classes, but differ with respect to residual maturity as follows (residual maturity, haircut): 0-1, 2.0; 1-3, 7.0; 3-5, 10.0; 5-7, 12.0; 7-10, 17.0; >10, 25.0.											

**Table 1 – continued**

*Panel B: Haircuts applied to eligible marketable assets (from October 25, 2008 to December 31, 2010)*

		<i>Liquidity categories for marketable assets</i>								
		<i>Category I</i>	<i>Category II</i>		<i>Category III</i>		<i>Category IV*</i>		<i>Category V*</i>	
		Central government debt instruments, Debt instruments issued by central banks	Local and regional government debt instruments, Jumbo covered bank bonds, Agency debt instruments, Supranational debt instruments		Traditional covered bank bonds, Debt instruments issued by corporate and other issuers		<i>Credit institution debt instruments (unsecured)*</i>		<i>Asset-backed securities*</i>	
<i>Credit quality</i> <sup>†</sup>	Residual maturity (years)	fixed coupon	zero coupon	fixed coupon	zero coupon	fixed coupon	zero coupon	fixed coupon	zero coupon	
	0-1	0.5	0.5	1.0	1.0	1.5	1.5	<i>6.5*</i>	<i>6.5*</i>	
	1-3	1.5	1.5	2.5	2.5	3.0	3.0	<i>8.0*</i>	<i>8.0*</i>	
<i>AAA to A-</i> <sup>†</sup>	3-5	2.5	3.0	3.5	4.0	4.5	5.0	<i>9.5*</i>	<i>10.0*</i>	
	5-7	3.0	3.5	4.5	5.0	5.5	6.0	<i>10.5*</i>	<i>11.0*</i>	<i>12*</i>
	7-10	4.0	4.5	5.5	6.5	6.5	8.0	<i>11.5*</i>	<i>13.0*</i>	
	>10	5.5	8.5	7.5	12.0	9.0	15.0	<i>14.0*</i>	<i>20.0*</i>	
<i>Floating rate debt instruments: For liquidity categories I to IV*, same as in Panel A.</i>										
<i>Inverse floating rate debt instruments: For liquidity categories I to IV* same as in Panel A.</i>										
<i>BBB+ to BBB-<sup>†</sup>: Add 5% to AAA to A- according to residual maturity, coupon structure and liquidity category except for ABS for which BBB- to BBB+ is not eligible.<sup>†</sup></i>										

**Table 2**

Aggregate collateral amount and liquidity uptake patterns from January 2006 to December 2010.

This table reports on various features of the aggregate collateral pool (of German banks) over time. Statistics are provided for the whole sample period (January 18, 2006 to December 31, 2010) as well as for five sub-periods: “2006”, “Pre-Crisis”, “Crisis to Lehman”, “Post-Lehman”, and “2010”, with dates as shown below. The whole sample period covers 60 maintenance periods. We observe at least one day in each maintenance period. Values of each variable are first averaged within each maintenance period. The reported numbers are averages of these maintenance period mean values (there are two exceptions to this procedure—both in Panel A).

Panel A: Collateral and credit are the aggregated collateral values and liquidity uptakes, respectively. The Eurosystem liquidity uptake is taken from the ECB’s webpage, <http://sdw.ecb.europa.eu/browse.do?node=bbn129>. “Coverage ratio, Germany” is collateral divided by credit in Germany, calculated from the numbers in the table, except for the total sample period where the ratio is a quantity weighted average of the sub-period values in the table (weights: number of maintenance periods). “Credit ratio Germany/Eurosystem” is German liquidity uptake as a fraction of the total Eurosystem uptake, calculated from the numbers in the table (the total sample period ratio is calculated as for the coverage ratio).

Panel B shows collateral pool weights of (1) different collateral types, (2) the issuers’ country of residence, and (3) of own-use collateral. Types are Government, Covered, Corporates, and “Uncovered etc.”. Country of residence is either Germany or PIIGSC (Portugal, Ireland, Italy, Greece, Spain, and Cyprus). Own-use refers to collateral issued by an entity with which the bank that holds it in the pool has “close links” (European Central Bank, 2005, and European Central Bank, 2010).

Panel C shows excess collateral ratios calculated as  $(collateral\ value - excluded\ collateral - credit)/(collateral\ value - excluded\ collateral)$ . First, we take all collateral into account (no subset is excluded). Second, we exclude “non-German” collateral, third, “Uncovered etc.”, and fourth, the latter together with collateral of PIIGSC issuers.

		<b>Total</b>	<b>2006</b>	<b>Pre-Crisis</b>	<b>Crisis to Lehman</b>	<b>Post-Lehman</b>	<b>2010</b>
		18.01.06 31.12.10	18.01.06 16.01.07	17.01.07 07.08.07	08.08.07 09.09.08	16.09.08 19.01.10	20.01.10 31.12.10
Number of banks (min – max)		45 – 1,387	864 – 981	202 – 859	203 – 862	801 – 1,387	45 – 1,383
Number of maintenance periods		60	12	7	13	16	12
Number of observed days		667	21	14	113	278	241
<i>Panel A: Collateral and liquidity uptake</i>							
Collateral, Germany	mEUR	616,517	494,536	516,887	596,291	728,599	669,086
Credit, Germany	mEUR	206,483	233,027	233,775	199,499	222,966	149,606
Credit, Eurosystem	mEUR	555,567	424,141	434,663	461,690	710,135	653,133
Coverage ratio, Germany	%	3.10	2.12	2.21	2.99	3.27	4.47
Credit ratio Germany/Eurosystem	%	39.58	54.94	53.78	43.21	31.40	22.91
<i>Panel B: Collateral pool weights</i>							
Government*	%	16.60	20.13	15.46	14.39	13.54	20.21
Covered**	%	22.60	28.03	24.62	22.13	20.88	18.81
Corporates	%	6.50	5.75	6.76	7.04	6.80	6.09
Uncovered etc.	%	54.29	46.09	53.16	56.44	58.75	54.87
Germany	%	54.49	55.21	46.98	45.03	58.51	63.04
PIIGSC	%	20.92	21.28	25.39	27.25	19.08	13.54
Own-use	%	6.47	1.71	1.40	1.38	11.12	13.51
<i>Panel C: Excess collateral given different exclude subsets</i>							
Nothing excluded	%	65.47	52.90	54.67	66.59	69.34	77.95
Excl. Non-German	%	34.27	14.44	3.04	25.66	46.82	64.91
Excl. Uncovered etc.	%	24.64	12.49	3.09	23.28	25.64	49.50
Excl. Uncovered etc. + PIIGSC	%	3.84	-11.65	-28.03	-3.33	3.66	45.95

\* By central, regional or local governments, or central banks, agencies, or supranationally issued debt instruments

\*\* Traditional and jumbo covered bank bonds

**Table 3**

Descriptive statistics: per sub-period and for the full sample period.

Descriptive statistics for normalized credit, collateral quality, financial health, normalized deposit flows, and concentration measures. The population is equally weighted averages across maintenance periods for each bank and sub-period (or the total sample period). Panel A covers the “Pre-Crisis”, Panel B the “Early Crisis”, Panel C the “Full Allotment”, and Panel D the full period. “SE” is standard errors. “SD” is standard deviation. “Med34” is either the average of the *four* observations around the median if the number of observed banks is even or, else, of the *three* observations around the median. “Min3” is the average of the smallest three observations. “Max3” is the equivalent for the largest three observations. “Number of banks” shows counts in total and by bank sectors. “Head” institutions are Landesbanks and Cooperative central banks.

The logarithm of total book assets measures bank size. Credit is normalized either by total assets, with assets taken from the end-of-month preceding each maintenance period, or by average daily reserve requirements in each maintenance period. Collateral quality measures are collateral haircut, duration, probability of default, liquidity category, and the fraction of own-use collateral. Financial health measures are equity ratio, write-offs & provisions, and ROA. Equity ratio is equity divided by total assets, both taken from the end-of-month preceding each maintenance period. Write-offs and provisions (ROA) are given as preceding year’s write-offs and provisions (income) divided by total assets, where assets are taken from the beginning of the preceding year. Deposit flows are contemporaneous and normalized in the same manner as credit is normalized. Deposit flows are separated into flows of banks and flows of non-banks. Concentration measures are the Herfindahl-Indices for collateral classes and issuer groups.

		<i>Panel A: Pre-Crisis</i>						<i>Panel B: Early Crisis</i>					
		January 1, 2006 – August 7, 2007						August 8, 2007 – September 9, 2008					
	Units	Mean	SE	SD	Med34	Min3	Max3	Mean	SE	SD	Med34	Min3	Max3
ln(assets)	Ln(Eur)	20.78	0.05	1.54	20.70	16.32	26.52	20.90	0.05	1.53	20.80	16.53	26.63
<b><i>Credit, normalized</i></b>													
By assets	%	1.39	0.11	3.25	0.04	0.00	32.86	1.27	0.09	2.72	0.10	0.00	21.23
By res. req.	%	335.99	96.27	2,854.31	4.30	0.00	44,600.07	319.60	89.71	2,589.06	8.25	0.00	41,312.02
<b><i>Collateral quality</i></b>													
Haircut	%	2.22	0.04	1.08	1.96	0.50	11.56	2.70	0.06	1.79	2.40	0.53	16.90
Duration	year	2.49	0.06	1.84	2.15	0.02	16.72	2.57	0.07	1.92	2.17	0.03	17.17
Prob. of default	bps	6.66	0.28	8.37	4.17	1.00	46.00	3.10	0.14	4.07	2.40	1.00	46.00
Liquidity category	1-6	2.69	0.02	0.55	2.76	1.00	4.35	2.92	0.02	0.67	3.00	1.00	5.33
Own-use	%	0.36	0.15	4.56	0.00	0.00	73.59	0.29	0.13	3.89	0.00	0.00	58.91
<b><i>Financial health</i></b>													
Equity ratio	%	5.56	0.14	4.05	5.12	0.52	60.33	5.58	0.13	3.68	5.21	0.48	54.87
Write-offs & prov.	%	0.53	0.02	0.54	0.49	0.00	6.65	0.49	0.01	0.31	0.48	0.00	2.63
ROA	%	0.18	0.05	1.46	0.17	-19.23	11.58	0.15	0.05	1.52	0.16	-20.88	10.28
<b><i>Deposit flow, normalized</i></b>													
Banks, by assets	%	0.03	0.02	0.51	-0.01	-2.44	5.12	0.23	0.03	0.77	0.09	-3.33	8.08
Non-banks, by assets	%	0.17	0.03	0.75	0.07	-0.99	9.54	0.36	0.07	2.13	0.16	-3.07	27.76
Banks, by res. req.	%	137.49	133.62	3,961.63	-1.42	-15,487.29	54,995.22	802.95	737.29	21,279.61	7.11	-18,533.81	229,923.25
Non-banks, by res. req.	%	35.02	17.23	510.96	6.20	-2,290.89	5,792.27	103.17	55.95	1,614.89	13.65	-858.48	18,609.47
<b><i>Concentration</i></b>													
HHI collateral class	%	65.71	0.82	24.34	60.84	20.42	100.00	65.77	0.83	23.95	60.80	17.95	100.00
HHI issuer group	%	85.53	0.63	18.73	97.71	28.44	100.00	84.34	0.67	19.48	94.44	25.25	100.00
Number of banks		Total:		879	Foreign:		11	Total:		833	Foreign:		11
		Private:		88	Head:		12	Private:		89	Head:		12
		Savings:		354	Private loan:		13	Savings:		334	Private loan:		13
		Cooperatives:		390	Special purpose:		11	Cooperatives:		363	Special purpose:		11

Table 3 – continued

		<i>Panel C: Full Allotment</i>						<i>Panel D: Full Period</i>					
		November 12, 2008 – November 9, 2010						January 1, 2006 – November 9, 2010*					
	Units	Mean	SE	SD	Med34	Min3	Max3	Mean	SE	SD	Med34	Min3	Max3
ln(assets)	Ln(Eur)	20.51	0.04	1.46	20.37	16.60	26.71	20.45	0.04	1.45	20.32	16.52	26.62
<b><i>Credit, normalized</i></b>													
By assets	%	2.60	0.08	2.88	1.82	0.00	23.32	2.16	0.07	2.59	1.41	0.00	22.30
By res. req.	%	409.52	79.54	2,906.12	145.15	0.00	50,974.22	366.15	75.70	2,791.59	116.76	0.00	47,301.43
<b><i>Collateral quality</i></b>													
Haircut	%	5.89	0.06	2.12	5.96	0.71	18.06	4.78	0.06	2.07	4.30	0.78	15.26
Duration	year	2.79	0.05	1.96	2.42	0.07	25.92	2.68	0.05	1.68	2.33	0.05	17.91
Prob. of default	bps	3.76	0.06	2.09	3.60	1.00	19.39	4.34	0.09	3.27	3.86	1.00	39.24
Liquidity category	1-6	3.35	0.02	0.60	3.45	1.01	5.29	3.18	0.02	0.59	3.21	1.00	5.01
Own-use	%	0.83	0.20	7.28	0.00	0.00	99.41	0.61	0.16	5.84	0.00	0.00	99.41
<b><i>Financial health</i></b>													
Equity ratio	%	5.56	0.07	2.69	5.25	0.45	41.80	5.63	0.09	3.21	5.27	0.48	56.79
Write-offs & prov.	%	0.45	0.01	0.30	0.41	0.00	2.76	0.47	0.01	0.29	0.45	0.00	3.35
ROA	%	0.05	0.06	2.24	0.15	-41.28	8.74	0.08	0.06	2.23	0.16	-38.41	12.49
<b><i>Deposit flow, normalized</i></b>													
Banks, by assets	%	0.08	0.06	2.13	-0.01	-6.79	34.66	0.07	0.02	0.60	0.01	-2.04	9.68
Non-banks, by assets	%	0.30	0.02	0.58	0.23	-2.81	5.96	0.29	0.02	0.61	0.18	-1.32	8.11
Banks, by res. req.	%	99.25	149.80	5,473.51	-1.40	-40,403.55	80,297.18	199.67	169.30	6,243.42	0.18	-8,565.04	94,637.31
Non-banks, by res. req.	%	9.07	8.45	308.56	18.78	-6,060.81	1,037.90	26.95	6.77	249.57	15.48	-2,547.89	3,462.38
<b><i>Concentration</i></b>													
HHI collateral class	%	63.73	0.62	22.60	60.68	20.70	100.00	66.13	0.56	20.59	64.09	21.46	100.00
HHI issuer group	%	79.61	0.53	19.25	83.08	30.02	100.00	82.46	0.46	16.94	86.20	32.05	100.00
Number of banks		Total:		1,335	Foreign:		11	Total:		1,360	Foreign:		12
		Private:		106	Head:		12	Private:		107	Head:		12
		Savings:		408	Private loan:		13	Savings:		416	Private loan:		13
		Cooperatives:		774	Special purpose:		11	Cooperatives:		789	Special purpose:		11

\*not covering September 10 – November 11, 2008

**Table 4**

Averages by bank size groups: per sub-period and the full sample period.

Averages of normalized credit, collateral quality, financial health, normalized deposit flows, and concentration measures by bank size groups. The population is equally weighted averages across maintenance periods for each bank and sub-period (or the total sample period). Panel A covers the “Pre-Crisis”, Panel B the “Early Crisis”, Panel C the “Full Allotment”, and Panel D the full period. We build five size groups according to the 25, 50, 75, and 99 percentiles by averaging each bank’s total assets across all 56 maintenance periods: <25%, 25-50%, 50-75%, 75-99%, and >99%. A bank does therefore not change its size group from one sub-period to another. A bank in size group 25-50%, for instance, has average size larger than the 25<sup>th</sup> and smaller than or equal to the 50<sup>th</sup> percentile.

The logarithm of total book assets measures bank size. Credit is normalized either by total assets, taken from the end-of-month preceding each maintenance period, or by average daily reserve requirements in each maintenance period. Collateral quality measures are haircut, duration, probability of default, liquidity category, and the fraction of own-use collateral. Financial health is measured by equity ratio, write-offs & provisions, and ROA. Equity ratio is equity divided by total assets, both taken from the end-of-month preceding each maintenance period. Write-offs and provisions (ROA) are given as preceding year’s write-offs and provisions (income) divided by total assets, where assets are taken from the beginning of the preceding year. Deposit flows are contemporaneous and normalized in the same manner as credit is normalized. Deposit flows are separated into flows of banks and flows of non-banks. Concentration measures are the Herfindahl-Indices for collateral classes and issuer groups. “n.a.” indicates that data is not available.

		<i>Panel A: Pre-Crisis</i>					<i>Panel B: Early Crisis</i>				
		January 1, 2006 – August 7, 2007					August 8, 2007 – September 9, 2008				
		<b>Size groups</b>					<b>Size groups</b>				
		<25%	25-50%	50-75%	75-99%	>99%	<25%	25-50%	50-75%	75-99%	>99%
Ln(assets)	Ln(Eur)	18.67	19.84	20.68	22.15	26.01	18.77	19.88	20.73	22.21	26.11
<b><i>Credit, normalized</i></b>											
By assets	%	0.59	0.93	1.37	1.96	3.17	0.48	1.07	1.33	1.59	2.57
By res. req.	%	53.20	366.15	128.51	598.85	977.21	42.02	300.82	126.66	583.85	597.44
<b><i>Collateral quality</i></b>											
Haircut	%	2.12	2.14	2.13	2.38	2.58	2.57	2.64	2.45	2.96	3.44
Duration	year	2.08	2.17	2.24	2.99	4.48	2.23	2.37	2.20	2.99	5.01
Prob. of default	bps	6.97	7.95	7.05	5.61	3.59	3.48	3.77	3.05	2.61	3.31
Liquidity category	1-6	2.70	2.61	2.61	2.79	2.94	2.96	2.90	2.81	2.99	3.35
Own-use	%	n.a.	n.a.	0.09	0.40	5.49	n.a.	n.a.	0.12	0.46	5.83
<b><i>Financial health</i></b>											
Equity ratio	%	7.07	6.03	5.29	4.85	4.34	7.20	5.92	5.43	4.91	4.24
Write-offs & prov.	%	0.51	0.55	0.59	0.50	0.17	0.47	0.55	0.52	0.46	0.29
ROA	%	-0.04	0.24	0.20	0.22	0.13	-0.14	0.23	0.19	0.19	0.19
<b><i>Deposit flow, normalized</i></b>											
Banks, by assets	%	0.01	-0.01	0.03	0.04	0.25	0.10	0.29	0.25	0.21	0.46
Non-banks, by assets	%	0.23	0.10	0.09	0.25	0.09	0.23	0.22	0.59	0.30	0.37
Banks, by res. req.	%	-11.81	-120.92	320.23	203.91	111.18	7.45	29.27	-201.63	2360.49	540.48
Non-banks, by res. req.	%	116.12	5.54	-12.12	53.47	21.00	18.82	18.41	40.35	223.41	322.68
<b><i>Concentration</i></b>											
HHI collateral class	%	79.33	71.41	64.27	58.28	41.58	78.65	71.75	66.43	57.93	39.80
HHI issuer group	%	92.58	88.60	84.92	82.10	60.02	93.47	86.78	85.46	79.81	53.73
Number of banks		143	171	252	299	14	122	162	237	298	14

Table 4 – continued

		<i>Panel C: Full Allotment</i>					<i>Panel D: Full Period</i>				
		November 12, 2008 – November 9, 2010					January 1, 2006 – November 9, 2010*				
		Size groups					Size groups				
		<25%	25-50%	50-75%	75-99%	>99%	<25%	25-50%	50-75%	75-99%	>99%
ln(assets)	Ln(Eur)	18.84	19.95	20.80	22.21	26.17	18.81	19.91	20.75	22.16	26.10
<b><i>Credit, normalized</i></b>											
By assets	%	2.42	2.82	2.69	2.50	1.61	2.03	2.33	2.14	2.11	2.36
By res. req.	%	204.68	262.60	526.43	646.17	423.06	171.49	275.66	474.89	537.97	649.33
<b><i>Collateral quality</i></b>											
Haircut	%	6.33	6.21	5.53	5.38	8.51	5.50	5.27	4.26	4.06	5.24
Duration	year	2.72	2.59	2.71	2.99	5.91	2.55	2.52	2.52	3.04	5.17
Prob. of default	bps	4.12	4.18	3.48	3.18	5.52	4.48	4.85	4.25	3.77	4.22
Liquidity category	1-6	3.43	3.44	3.27	3.26	3.91	3.31	3.27	3.05	3.07	3.42
Own-use	%	n.a.	n.a.	0.50	2.44	9.64	n.a.	n.a.	0.46	1.61	7.54
<b><i>Financial health</i></b>											
Equity ratio	%	6.45	5.72	5.34	4.78	4.58	6.47	5.82	5.31	4.94	4.42
Write-offs & prov.	%	0.42	0.47	0.48	0.44	0.49	0.44	0.49	0.51	0.46	0.33
ROA	%	0.01	0.01	0.15	0.01	-0.02	0.05	0.03	0.18	0.09	0.08
<b><i>Deposit flow, normalized</i></b>											
Banks, by assets	%	0.27	0.02	0.09	-0.03	-0.29	0.09	0.05	0.10	0.05	0.05
Non-banks, by assets	%	0.29	0.33	0.35	0.24	0.04	0.28	0.29	0.32	0.26	0.13
Banks, by res. req.	%	36.86	-52.22	-294.86	731.16	-80.08	8.01	-38.44	-16.26	878.54	73.39
Non-banks, by res. req.	%	23.82	24.19	11.56	-22.19	-30.32	30.53	21.83	3.26	53.01	33.24
<b><i>Concentration</i></b>											
HHI collateral class	%	73.81	67.39	62.02	52.64	39.60	75.78	69.37	64.29	55.71	40.20
HHI issuer group	%	83.08	80.42	80.42	75.72	50.21	85.58	83.35	83.24	78.66	54.23
Number of banks		326	336	334	325	14	340	340	340	326	14

\*not covering Sept. 10 – Nov. 11, 2008

**Table 5**

Tobit panel regressions of normalized credit on size, collateral quality, financial health, deposit flow, and concentration.

Panel A represents separate regressions carried out on the population of bank-maintenance period observations for the “Pre-Crisis”, the “Early Crisis”, the “Full Allotment”, and the total period, respectively. Each regression includes bank sector and maintenance period fixed effects (not reported). Bank sectors are “private banks”, “savings banks”, “cooperatives”, “foreign banks”, “landesbanks”, “cooperative central banks”, “private loan banks”, and “special purpose banks”. We report tobit coefficients. In Panel B we decompose the tobit coefficients into the effects of a one unit change in the independent variable on (1) the change in *probability of taking credit*, “PoC”, and (2) the unit change in normalized *credit conditional on* a bank taking *credit*, “CCoC”. We calculate average marginal effects with observed values on the other independent variables.

The dependent variable is normalized credit (in percent; normalized by total assets taken from the end-of-month preceding each maintenance period). For variables subscripted by  $m - 1$  and  $y - 1$ , values are taken from the end-of-month and the end-of-year preceding each maintenance period, respectively. Ln(assets) measures bank size. Haircut measures collateral quality. Financial health is measured by equity ratio, write-offs & provisions, and ROA. Deposit flows are contemporaneous, normalized in the same manner as credit is normalized, and separated into flows of banks and flows of non-banks. The Herfindahl index (HHI) for issuer group measures concentration of a bank’s collateral pool. For the period labelled “Total,” note that observations in the period September 10 to November 11, 2008, are dropped.

Underneath the coefficients in Panel A (marginal effects in Panel B) we report, in parentheses,  $t$ -statistics ( $z$ -statistics) with standard errors clustered on the banks.  $a$ ,  $b$ , and  $c$  denote significance (two-tailed) at 1%, 5%, and 10% level with, first, standard errors clustered on the banks and, second, Huber-White corrected standard errors (in square brackets).

	<i>Panel A: Tobit coefficients</i>				<i>Panel B: Average marginal effects</i>				
	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>	<i>Change</i>	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>
	18.01.06-07.08.07	08.08.07-09.09.08	12.11.08-09.11.10	18.01.06-09.11.10		18.01.06-07.08.07	08.08.07-09.09.08	12.11.08-09.11.10	18.01.06-09.11.10
ln(assets) <sub><math>m-1</math></sub> [ln(Eur)]	1.165 <sup>a,[a]</sup> (4.02)	0.987 <sup>a,[a]</sup> (4.81)	0.112 <sup>·,[a]</sup> (1.05)	0.486 <sup>a,[a]</sup> (3.94)	PoC	0.055 <sup>a,[a]</sup> (5.13)	0.051 <sup>a,[a]</sup> (5.05)	0.008 <sup>·,[a]</sup> (1.05)	0.032 <sup>a,[a]</sup> (4.14)
					CCoC	0.328 <sup>a,[a]</sup> (4.15)	0.277 <sup>a,[a]</sup> (4.81)	0.050 <sup>·,[a]</sup> (1.05)	0.178 <sup>a,[a]</sup> (3.98)
Haircut [%]	0.527 <sup>a,[a]</sup> (3.98)	0.283 <sup>a,[a]</sup> (2.76)	0.162 <sup>a,[a]</sup> (3.14)	0.260 <sup>a,[a]</sup> (5.24)	PoC	0.025 <sup>a,[a]</sup> (3.66)	0.015 <sup>a,[a]</sup> (2.67)	0.012 <sup>a,[a]</sup> (3.14)	0.017 <sup>a,[a]</sup> (5.40)
					CCoC	0.148 <sup>a,[a]</sup> (4.01)	0.079 <sup>a,[a]</sup> (2.75)	0.073 <sup>a,[a]</sup> (3.14)	0.095 <sup>a,[a]</sup> (5.28)
Equity ratio <sub><math>m-1</math></sub> [%]	-0.624 <sup>c,[a]</sup> (-1.95)	-0.292 <sup>·,[a]</sup> (-1.49)	-0.387 <sup>a,[a]</sup> (-3.59)	-0.411 <sup>a,[a]</sup> (-3.00)	PoC	-0.025 <sup>b,[a]</sup> (-2.06)	-0.012 <sup>·,[a]</sup> (-1.33)	-0.024 <sup>a,[a]</sup> (-3.57)	-0.023 <sup>a,[a]</sup> (-2.93)
					CCoC	-0.150 <sup>c,[a]</sup> (-1.90)	-0.064 <sup>·,[a]</sup> (-1.31)	-0.147 <sup>a,[a]</sup> (-3.54)	-0.126 <sup>a,[a]</sup> (-2.86)
Equity ratio <sub><math>m-1</math></sub> <sup>2</sup>	0.009 <sup>b,[a]</sup> (2.13)	0.006 <sup>b,[a]</sup> (2.44)	0.006 <sup>a,[a]</sup> (2.93)	0.006 <sup>a,[a]</sup> (3.39)					Not applicable
Write-offs & prov <sub><math>y-1</math></sub> [%]	-1.205 <sup>c,[b]</sup> (-1.70)	-1.357 <sup>b,[a]</sup> (-2.39)	0.902 <sup>a,[a]</sup> (2.61)	-0.200 <sup>·,[a]</sup> (-0.89)	PoC	-0.057 <sup>c,[b]</sup> (-1.78)	-0.071 <sup>b,[a]</sup> (-2.48)	0.068 <sup>a,[a]</sup> (2.66)	-0.013 <sup>·,[a]</sup> (-0.90)
					CCoC	-0.339 <sup>c,[b]</sup> (-1.70)	-0.380 <sup>b,[a]</sup> (-2.40)	0.405 <sup>a,[a]</sup> (2.61)	-0.073 <sup>·,[a]</sup> (-0.89)
ROA <sub><math>y-1</math></sub> [%]	-0.014 (-0.09)	0.028 (0.27)	-0.004 (-0.04)	0.004 (0.05)	PoC	-0.001 (-0.09)	0.001 (0.27)	-0.000 (-0.04)	0.000 (0.05)
					CCoC	-0.004 (-0.09)	0.008 (0.27)	-0.002 (-0.04)	0.002 (0.05)

**Table 5** – *continued*

	<i>Panel A: Tobit Coefficients</i>				<i>Panel B: Average marginal effects</i>				
	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>	<i>Change</i>	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>
	18.01.06-07.08.07	08.08.07-09.09.08	12.11.08-09.11.10	18.01.06-09.11.10		18.01.06-07.08.07	08.08.07-09.09.08	12.11.08-09.11.10	18.01.06-09.11.10
Deposit flow banks [%]	0.147 <sup>c,[b]</sup> (1.74)	0.162 <sup>c,[b]</sup> (1.96)	-0.009 (-0.75)	0.019 (1.16)	PoC	0.007 <sup>b,[b]</sup> (2.02)	0.008 <sup>c,[b]</sup> (1.84)	-0.001 (-0.75)	0.001 (1.16)
					CCoC	0.041 <sup>c,[b]</sup> (1.76)	0.045 <sup>c,[b]</sup> (1.94)	-0.004 (-0.75)	0.007 (1.16)
Deposit flow non-banks [%]	-0.075 <sup>c,[c]</sup> (-1.54)	-0.112 <sup>b,[b]</sup> (-2.43)	0.016 (0.90)	-0.006 (-0.44)	PoC	-0.004 <sup>c,[c]</sup> (-1.65)	-0.006 <sup>b,[b]</sup> (-2.47)	0.001 (0.90)	-0.000 (-0.44)
					CCoC	-0.021 <sup>c,[c]</sup> (-1.55)	-0.032 <sup>b,[b]</sup> (-2.43)	0.007 (0.90)	-0.002 (-0.44)
HHI issuer group [%]	-0.094 <sup>a,[a]</sup> (-5.24)	-0.055 <sup>a,[a]</sup> (-4.51)	-0.017 <sup>a,[a]</sup> (-3.41)	-0.040 <sup>a,[a]</sup> (-6.14)	PoC	-0.004 <sup>a,[a]</sup> (-8.36)	-0.003 <sup>a,[a]</sup> (-5.17)	-0.001 <sup>a,[a]</sup> (-3.42)	-0.003 <sup>a,[a]</sup> (-7.06)
					CCoC	-0.026 <sup>a,[a]</sup> (-5.37)	-0.015 <sup>a,[a]</sup> (-4.53)	-0.008 <sup>a,[a]</sup> (-3.42)	-0.015 <sup>a,[a]</sup> (-6.30)
Constant	-17.657 <sup>a,[a]</sup> (-2.91)	-16.761 <sup>a,[a]</sup> (-3.29)	1.801 <sup>c,[b]</sup> (0.68)	-6.950 <sup>b,[a]</sup> (-2.32)		Not applicable			
Sigma constant	6.777 <sup>a,[a]</sup> (9.31)	6.133 <sup>a,[a]</sup> (14.36)	4.545 <sup>a,[a]</sup> (27.62)	5.299 <sup>a,[a]</sup> (18.89)		Not applicable			
Bank sector fixed effects	yes	yes	yes	yes					
Maintenance period fixed effects	yes	yes	yes	yes					
# of maintenance periods	19	13	24	56		As in Panel A			
# of observations	14,886	9,453	29,494	53,833					
Pseudo R-squared	0.052	0.056	0.040	0.052		Not applicable			

**Table 6**

Decomposition of haircut – correlations between indicated variables and regressions of haircut on them.

The population is bank-maintenance period observations. Panel A shows correlations between indicated variables (haircut ingredients), which are duration, probability of default, and liquidity category of collateral. The correlations are shown for the “Pre-Crisis”, the “Early Crisis”, the “Full Allotment”, and the total period. For the period labelled “Total,” note that observations in the period September 10 to November 11, 2008, are dropped.

In Panel B, each column represents a separate panel regression of haircut (in percent) on indicated variables for the same sub-periods and the total period. Each regression includes maintenance period fixed effects. Standard errors are Huber-White corrected. *t*-statistics are in brackets underneath the coefficients. *a*, *b*, and *c* denote significance (two-tailed) at 1%, 5%, and 10% level, respectively.

		<i>Panel A: Correlations of indicated variables per sub period and the full period</i>					
		Duration	Prob. of default	Liquidity category	Duration	Prob. of default	Liquidity category
		<i>Pre-Crisis</i>			<i>Early Crisis</i>		
Duration	year	1			1		
Prob. of default	bps	-0.273	1		-0.058	1	
Liquidity category	1-6	-0.035	-0.175	1	0.026	0.512	1
		<i>Full Allotment</i>			<i>Total</i>		
Duration	year	1			1		
Prob. of default	bps	-0.072	1		-0.137	1	
Liquidity category	1-6	-0.045	0.527	1	-0.025	0.285	1
		<i>Panel B: Panel with maintenance period fixed effects of haircut on ingredients</i>					
		<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allotment</i>	<i>Total</i>		
		18.01.06-07.08.07	08.08.07-09.09.08	12.11.08-09.11.10	18.01.06-09.11.10		
Duration	year	0.293 <sup>a</sup> (48.21)	0.228 <sup>a</sup> (15.72)	0.256 <sup>a</sup> (21.72)	0.264 <sup>a</sup> (34.96)		
Prob. of default	bps	-0.003 <sup>a</sup> (-3.54)	0.052 <sup>a</sup> (6.23)	0.151 <sup>a</sup> (33.36)	0.034 <sup>a</sup> (34.10)		
Liquidity category	1-6	0.628 <sup>a</sup> (16.58)	1.001 <sup>a</sup> (18.18)	2.397 <sup>a</sup> (114.45)	1.812 <sup>a</sup> (99.88)		
Constant		-0.172 <sup>c</sup> (-1.65)	-0.964 <sup>a</sup> (-6.21)	-3.458 <sup>a</sup> (-44.66)	-2.155 <sup>a</sup> (-34.79)		
# of maintenance periods		19	13	24	56		
# of observations		14,886	9,453	29,494	53,833		
Adj. R-squared		0.320	0.236	0.673	0.696		

**Table 7**

Tobit panel regressions of normalized credit on size, haircut decomposing collateral quality measures, financial health, deposit flow, and concentration.

Panel A represents separate regressions carried out on the population of bank-maintenance period observations for the “Pre-Crisis”, the “Early Crisis”, the “Full Allotment”, and the total period, respectively. Each regression includes bank sector and maintenance period fixed effects (not reported). Bank sectors are “private banks”, “savings banks”, “cooperatives”, “foreign banks”, “landesbanks”, “cooperative central banks”, “private loan banks”, and “special purpose banks”. We report tobit coefficients. In Panel B we decompose the tobit coefficients into the effects of a one unit change in the independent variable on (1) the change in *probability of taking credit*, “PoC”, and (2) the unit change in normalized *credit conditional on* a bank taking *credit*, “CCoC”. We calculate average marginal effects with observed values on the other independent variables.

The dependent variable is normalized credit (in percent; normalized by total assets taken from the end-of-month preceding each maintenance period). For variables subscripted by  $m - 1$  and  $y - 1$ , values are taken from the end-of-month and the end-of-year preceding each maintenance period, respectively. Ln(assets) measures bank size. Collateral quality is measured by the haircut composition measures (liquidity category, probability of default, and duration), the residual of an OLS regression of haircut on the haircut composition measures (per maintenance period), and the fraction of own-use collateral. Financial health is measured by equity ratio, write-offs & provisions, and ROA. Deposit flows are contemporaneous, normalized in the same manner as credit is normalized, and separated into flows of banks and flows of non-banks. The Herfindahl index (HHI) for issuer group measures concentration of a bank’s collateral pool. For the period labelled “Total,” note that observations in the period September 10 to November 11, 2008, are dropped.

Underneath the coefficients in Panel A (marginal effects in Panel B) we report, in parentheses,  $t$ -statistics ( $z$ -statistics) with standard errors clustered on the banks.  $a$ ,  $b$ , and  $c$  denote significance (two-tailed) at 1%, 5%, and 10% level with, first, standard errors clustered on the banks and, second, Huber-White corrected standard errors (in square brackets).

	<i>Panel A: Tobit coefficients</i>				<i>Panel B: Average marginal effects</i>				
	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>	<i>Change</i>	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>
	18.01.06- 07.08.07	08.08.07- 09.09.08	12.11.08- 09.11.10	18.01.06- 09.11.10		18.01.06- 07.08.07	08.08.07- 09.09.08	12.11.08- 09.11.10	18.01.06- 09.11.10
ln(assets) <sub><math>m-1</math></sub> [ln(Eur)]	0.933 <sup>a,[a]</sup> (3.47)	0.865 <sup>a,[a]</sup> (4.32)	0.100 <sup>·,[a]</sup> (0.93)	0.403 <sup>a,[a]</sup> (3.31)	PoC	0.044 <sup>a,[a]</sup> (4.11)	0.045 <sup>a,[a]</sup> (4.45)	0.008 <sup>·,[a]</sup> (0.93)	0.027 <sup>a,[a]</sup> (3.44)
					CCoC	0.263 <sup>a,[a]</sup> (3.55)	0.243 <sup>a,[a]</sup> (4.31)	0.045 <sup>·,[a]</sup> (0.93)	0.148 <sup>a,[a]</sup> (3.34)
Liquidity category [1-6]	2.879 <sup>a,[a]</sup> (5.21)	1.689 <sup>a,[a]</sup> (4.61)	0.962 <sup>a,[a]</sup> (4.10)	1.839 <sup>a,[a]</sup> (7.48)	PoC	0.137 <sup>a,[a]</sup> (6.45)	0.088 <sup>a,[a]</sup> (5.14)	0.072 <sup>a,[a]</sup> (4.12)	0.121 <sup>a,[a]</sup> (8.80)
					CCoC	0.813 <sup>a,[a]</sup> (5.30)	0.475 <sup>a,[a]</sup> (4.59)	0.435 <sup>a,[a]</sup> (4.10)	0.677 <sup>a,[a]</sup> (7.64)
Prob. of default [bps]	0.070 <sup>a,[a]</sup> (2.68)	0.227 <sup>a,[a]</sup> (3.43)	0.145 <sup>b,[a]</sup> (2.24)	0.025 <sup>·,[a]</sup> (1.37)	PoC	0.003 <sup>a,[a]</sup> (2.91)	0.012 <sup>a,[a]</sup> (3.54)	0.011 <sup>b,[a]</sup> (2.27)	0.002 <sup>·,[a]</sup> (1.37)
					CCoC	0.020 <sup>a,[a]</sup> (2.69)	0.064 <sup>a,[a]</sup> (3.42)	0.065 <sup>b,[a]</sup> (2.25)	0.009 <sup>·,[a]</sup> (1.37)
Duration [year]	0.530 <sup>a,[a]</sup> (3.91)	0.217 <sup>·,[a]</sup> (1.61)	-0.213 <sup>a,[a]</sup> (-3.73)	-0.003 (-0.03)	PoC	0.025 <sup>a,[a]</sup> (4.61)	0.011 <sup>·,[a]</sup> (1.61)	-0.016 <sup>a,[a]</sup> (-3.78)	-0.000 (-0.03)
					CCoC	0.150 <sup>a,[a]</sup> (3.99)	0.061 <sup>·,[a]</sup> (1.61)	-0.096 <sup>a,[a]</sup> (-3.73)	-0.001 (-0.03)
OLS resid. (per cross-sect.)	-0.146 <sup>·,[b]</sup> (-0.85)	-0.155 <sup>·,[a]</sup> (-1.17)	-0.155 <sup>c,[a]</sup> (-1.84)	-0.182 <sup>b,[a]</sup> (-2.13)	PoC	-0.007 <sup>·,[b]</sup> (-0.89)	-0.008 <sup>·,[a]</sup> (-1.21)	-0.012 <sup>c,[a]</sup> (-1.86)	-0.012 <sup>b,[a]</sup> (-2.22)
					CCoC	-0.041 <sup>·,[b]</sup> (-0.85)	-0.044 <sup>·,[a]</sup> (-1.17)	-0.070 <sup>c,[a]</sup> (-1.84)	-0.067 <sup>b,[a]</sup> (-2.14)
Own use [%]	-0.011 (-0.32)	-0.009 (-0.38)	0.049 <sup>c,[a]</sup> (1.87)	0.018 <sup>·,[a]</sup> (0.67)	PoC	-0.001 (-0.32)	-0.000 (-0.38)	0.004 <sup>c,[a]</sup> (1.87)	0.001 <sup>·,[a]</sup> (0.67)
					CCoC	-0.003 (-0.32)	-0.002 (-0.38)	0.022 <sup>c,[a]</sup> (1.87)	0.007 <sup>·,[a]</sup> (0.67)

Table 7 – continued

	<i>Panel A: Tobit coefficients</i>				<i>Panel B: Average marginal effects</i>				
	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>	<i>Change</i>	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>
	18.01.06-07.08.07	08.08.07-09.09.08	12.11.08-09.11.10	18.01.06-09.11.10		18.01.06-07.08.07	08.08.07-09.09.08	12.11.08-09.11.10	18.01.06-09.11.10
Equity ratio <sub>m-1</sub> [%]	-0.599 <sup>c,[a]</sup> (-1.78)	-0.221 <sup>c,[a]</sup> (-1.07)	-0.413 <sup>a,[a]</sup> (-3.84)	-0.413 <sup>a,[a]</sup> (-2.81)	PoC	-0.024 <sup>c,[a]</sup> (-1.82)	-0.009 <sup>c,[a]</sup> (-0.91)	-0.026 <sup>a,[a]</sup> (-3.78)	-0.023 <sup>a,[a]</sup> (-2.70)
					CCoC	-0.142 <sup>c,[a]</sup> (-1.71)	-0.046 <sup>c,[a]</sup> (-0.90)	-0.157 <sup>a,[a]</sup> (-3.74)	-0.126 <sup>a,[a]</sup> (-2.63)
Equity ratio <sub>m-1</sub> <sup>2</sup>	0.009 <sup>b,[a]</sup> (2.13)	0.005 <sup>b,[a]</sup> (2.10)	0.006 <sup>a,[a]</sup> (3.15)	0.007 <sup>a,[a]</sup> (3.49)					Not applicable
Write-offs & prov <sub>y-1</sub> [%]	-0.914 <sup>c,[c]</sup> (-1.34)	-1.253 <sup>b,[a]</sup> (-2.34)	0.815 <sup>a,[a]</sup> (2.58)	-0.160 <sup>c,[b]</sup> (-0.77)	PoC	-0.044 <sup>c,[c]</sup> (-1.37)	-0.065 <sup>b,[a]</sup> (-2.41)	0.061 <sup>a,[a]</sup> (2.63)	-0.011 <sup>c,[b]</sup> (-0.78)
					CCoC	-0.258 <sup>c,[c]</sup> (-1.34)	-0.352 <sup>b,[a]</sup> (-2.34)	0.368 <sup>a,[a]</sup> (2.59)	-0.059 <sup>c,[b]</sup> (-0.77)
ROA <sub>y-1</sub> [%]	0.033 (0.18)	0.055 (0.42)	-0.004 (-0.03)	0.008 (0.09)	PoC	0.002 (0.18)	0.003 (0.42)	-0.000 (-0.03)	0.001 (0.09)
					CCoC	0.009 (0.18)	0.016 (0.42)	-0.002 (-0.03)	0.003 (0.09)
Deposit flow banks [%]	0.161 <sup>b,[a]</sup> (1.97)	0.153 <sup>c,[b]</sup> (1.92)	-0.001 (-0.12)	0.020 (1.11)	PoC	0.008 <sup>b,[a]</sup> (2.35)	0.008 <sup>c,[b]</sup> (1.81)	-0.000 (-0.12)	0.001 (1.11)
					CCoC	0.045 <sup>b,[a]</sup> (2.00)	0.043 <sup>c,[b]</sup> (1.90)	-0.001 (-0.12)	0.007 (1.11)
Deposit flow non-banks [%]	-0.080 <sup>c,[b]</sup> (-1.71)	-0.109 <sup>b,[b]</sup> (-2.23)	0.016 (0.92)	-0.003 (-0.25)	PoC	-0.004 <sup>c,[b]</sup> (-1.85)	-0.006 <sup>b,[b]</sup> (-2.26)	0.001 (0.92)	-0.000 (-0.26)
					CCoC	-0.022 <sup>c,[b]</sup> (-1.72)	-0.031 <sup>b,[b]</sup> (-2.24)	0.007 (0.92)	-0.001 (-0.25)
HHI issuer group [%]	-0.104 <sup>a,[a]</sup> (-5.57)	-0.060 <sup>a,[a]</sup> (-4.76)	-0.031 <sup>a,[a]</sup> (-5.61)	-0.056 <sup>a,[a]</sup> (-7.70)	PoC	-0.005 <sup>a,[a]</sup> (-8.81)	-0.003 <sup>a,[a]</sup> (-5.46)	-0.002 <sup>a,[a]</sup> (-5.70)	-0.004 <sup>a,[a]</sup> (-9.51)
					CCoC	-0.029 <sup>a,[a]</sup> (-5.72)	-0.017 <sup>a,[a]</sup> (-4.79)	-0.014 <sup>a,[a]</sup> (-5.64)	-0.021 <sup>a,[a]</sup> (-7.98)
Constant	-20.503 <sup>a,[a]</sup> (-3.41)	-19.561 <sup>a,[a]</sup> (-3.96)	0.575 (0.21)	-8.319 <sup>a,[a]</sup> (-2.82)					Not applicable
Sigma constant	6.586 <sup>a,[a]</sup> (9.52)	5.955 <sup>a,[a]</sup> (15.10)	4.469 <sup>a,[a]</sup> (28.13)	5.219 <sup>a,[a]</sup> (19.29)					Not applicable
Bank sector fixed effects	yes	yes	yes	yes					
Maintenance period fixed effects	yes	yes	yes	yes					As in Panel A
# of maintenance periods	19	13	24	56					
# of observations	14,886	9,453	29,494	53,833					
Pseudo R-squared	0.063	0.067	0.047	0.058					Not applicable

**Table 8**

Heckman selection regressions of collateral quality measures on size and financial health.

In each Panel the four columns represent separate regressions carried out on the population of bank-maintenance period observations for the “Pre-Crisis”, the “Early Crisis”, the “Full Allotment”, and the total period, respectively. The selection equation controls for banks having positive liquidity uptake. The dependent variables in the main regressions are the haircut (Panel A, in percent) and its components (Panel B: probability of default, in bps; Panel C: liquidity category, 1 – 6; Panel D: duration, in years). For variables subscripted by  $m - 1$  and  $y - 1$ , values are taken from the end-of-month and the end-of-year preceding each maintenance period, respectively. Subscript  $j - 1$  refers to the previous maintenance period. Ln(assets) measures bank size. Financial health is measured by equity ratio, write-offs & provisions, and ROA. All regressions (main and selection) include bank sector (private banks, savings banks, cooperatives, foreign banks, landesbanks, cooperative central banks, private loan banks, special purpose banks) and maintenance period fixed effects (not reported).  $z$ -statistics, based on bank-clustered standard errors, are in parentheses underneath the coefficients.  $a$ ,  $b$ , and  $c$  denote significance (two-tailed) at 1%, 5%, and 10% levels. Significance levels based on Huber-White corrected standard errors are in square brackets. For the period labelled “Total,” observations in the period September 10 to November 11, 2008, are dropped.

		<i>Panel A: Haircut</i>				<i>Panel B: Probability of default</i>			
		<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>
		18.01.06- 07.08.07	08.08.07- 09.09.08	12.11.08- 09.11.10	18.01.06- 09.11.10	18.01.06- 07.08.07	08.08.07- 09.09.08	12.11.08- 09.11.10	18.01.06- 09.11.10
<i>Main equation</i>									
ln(assets) <sub><math>m-1</math></sub>	ln(Eur)	0.008 (0.12)	0.107 <sup>·</sup> , <sup>[a]</sup> (0.95)	-0.184 <sup>b</sup> , <sup>[a]</sup> (-2.28)	-0.098 <sup>·</sup> , <sup>[a]</sup> (-1.37)	-0.487 <sup>b</sup> , <sup>[a]</sup> (-2.31)	-0.231 <sup>a</sup> , <sup>[a]</sup> (-3.10)	-0.311 <sup>a</sup> , <sup>[a]</sup> (-5.27)	-0.328 <sup>a</sup> , <sup>[a]</sup> (-5.27)
Equity ratio <sub><math>m-1</math></sub>	%	-0.033 <sup>b</sup> , <sup>[a]</sup> (-2.56)	-0.019 <sup>·</sup> , <sup>[a]</sup> (-0.96)	-0.038 <sup>·</sup> , <sup>[a]</sup> (-0.98)	-0.035 <sup>·</sup> , <sup>[a]</sup> (-1.56)	-0.118 <sup>b</sup> , <sup>[a]</sup> (-2.28)	-0.054 <sup>a</sup> , <sup>[a]</sup> (-2.87)	0.004 (0.11)	-0.038 <sup>·</sup> , <sup>[a]</sup> (-1.19)
Write-offs & prov <sub><math>y-1</math></sub>	%	0.313 <sup>c</sup> , <sup>[a]</sup> (1.66)	0.184 (0.51)	0.220 <sup>·</sup> , <sup>[a]</sup> (1.55)	0.188 <sup>·</sup> , <sup>[a]</sup> (1.48)	-0.072 (-0.10)	0.059 (0.21)	0.451 <sup>b</sup> , <sup>[a]</sup> (2.45)	0.514 <sup>a</sup> , <sup>[a]</sup> (2.76)
ROA <sub><math>y-1</math></sub>	%	-0.030 (-0.18)	-0.031 <sup>·</sup> , <sup>[b]</sup> (-0.96)	0.049 <sup>·</sup> , <sup>[c]</sup> (1.03)	0.038 <sup>·</sup> , <sup>[c]</sup> (1.14)	0.057 (0.12)	0.088 <sup>a</sup> , <sup>[a]</sup> (3.55)	0.098 <sup>·</sup> , <sup>[a]</sup> (1.58)	0.066 <sup>·</sup> , <sup>[b]</sup> (1.12)
Constant		3.189 <sup>b</sup> , <sup>[a]</sup> (2.04)	1.005 (0.44)	7.023 <sup>a</sup> , <sup>[a]</sup> (4.45)	4.939 <sup>a</sup> , <sup>[a]</sup> (3.55)	17.749 <sup>a</sup> , <sup>[a]</sup> (3.65)	9.681 <sup>a</sup> , <sup>[a]</sup> (5.62)	10.878 <sup>a</sup> , <sup>[a]</sup> (7.65)	14.581 <sup>a</sup> , <sup>[a]</sup> (9.75)
<i>Selection equation: bank has positive liquidity uptake in maintenance period <math>j</math></i>									
Positive liquidity uptake <sub><math>j-1</math></sub>		2.829 <sup>a</sup> , <sup>[a]</sup> (47.79)	2.378 <sup>a</sup> , <sup>[a]</sup> (42.20)	2.988 <sup>a</sup> , <sup>[a]</sup> (68.37)	2.824 <sup>a</sup> , <sup>[a]</sup> (81.79)	2.829 <sup>a</sup> , <sup>[a]</sup> (47.77)	2.378 <sup>a</sup> , <sup>[a]</sup> (42.22)	2.990 <sup>a</sup> , <sup>[a]</sup> (68.40)	2.825 <sup>a</sup> , <sup>[a]</sup> (81.75)
ln(assets) <sub><math>m-1</math></sub>	ln(Eur)	0.125 <sup>a</sup> , <sup>[a]</sup> (7.09)	0.133 <sup>a</sup> , <sup>[a]</sup> (7.39)	0.037 <sup>b</sup> , <sup>[a]</sup> (2.54)	0.077 <sup>a</sup> , <sup>[a]</sup> (6.77)	0.125 <sup>a</sup> , <sup>[a]</sup> (7.10)	0.134 <sup>a</sup> , <sup>[a]</sup> (7.42)	0.037 <sup>b</sup> , <sup>[a]</sup> (2.55)	0.076 <sup>a</sup> , <sup>[a]</sup> (6.73)
Equity ratio <sub><math>m-1</math></sub>	%	-0.004 (-0.52)	0.001 (0.21)	-0.008 (-1.16)	-0.004 (-0.74)	-0.004 (-0.52)	0.001 (0.21)	-0.007 (-1.05)	-0.004 (-0.77)
Write-offs & prov <sub><math>y-1</math></sub>	%	-0.115 <sup>b</sup> , <sup>[a]</sup> (-2.48)	-0.128 <sup>b</sup> , <sup>[b]</sup> (-2.42)	0.019 (0.48)	-0.056 <sup>b</sup> , <sup>[a]</sup> (-2.09)	-0.114 <sup>b</sup> , <sup>[a]</sup> (-2.48)	-0.128 <sup>b</sup> , <sup>[b]</sup> (-2.42)	0.019 (0.48)	-0.055 <sup>b</sup> , <sup>[a]</sup> (-2.07)
ROA <sub><math>y-1</math></sub>	%	-0.003 (-0.26)	-0.010 (-1.00)	-0.014 (-1.10)	-0.009 (-1.12)	-0.003 (-0.25)	-0.010 (-1.02)	-0.013 (-1.10)	-0.008 (-1.09)
Constant		-4.907 <sup>a</sup> , <sup>[a]</sup> (-11.90)	-4.008 <sup>a</sup> , <sup>[a]</sup> (-9.92)	-2.083 <sup>a</sup> , <sup>[a]</sup> (-6.10)	-3.881 <sup>a</sup> , <sup>[a]</sup> (-14.24)	-4.905 <sup>a</sup> , <sup>[a]</sup> (-11.93)	-4.003 <sup>a</sup> , <sup>[a]</sup> (-9.96)	-2.086 <sup>a</sup> , <sup>[a]</sup> (-6.17)	-3.862 <sup>a</sup> , <sup>[a]</sup> (-14.25)
atanh $\rho$		-0.064 <sup>a</sup> , <sup>[a]</sup> (-2.70)	-0.066 <sup>c</sup> , <sup>[b]</sup> (-1.92)	-0.031 (-0.98)	-0.055 <sup>a</sup> , <sup>[a]</sup> (-2.79)	0.016 (0.43)	-0.117 <sup>a</sup> , <sup>[a]</sup> (-3.24)	-0.088 <sup>a</sup> , <sup>[a]</sup> (-3.74)	-0.022 <sup>·</sup> , <sup>[c]</sup> (-1.29)
ln( $\sigma$ )		0.348 <sup>a</sup> , <sup>[a]</sup> (3.27)	0.806 <sup>a</sup> , <sup>[a]</sup> (7.01)	0.700 <sup>a</sup> , <sup>[a]</sup> (14.50)	0.681 <sup>a</sup> , <sup>[a]</sup> (12.30)	1.768 <sup>a</sup> , <sup>[a]</sup> (18.25)	0.606 <sup>a</sup> , <sup>[a]</sup> (14.04)	0.723 <sup>a</sup> , <sup>[a]</sup> (22.19)	1.144 <sup>a</sup> , <sup>[a]</sup> (17.33)
# maintenance periods		18	13	23	54	18	13	23	54
# of observations		14,038	9,453	28,393	51,884	14,038	9,453	28,393	51,884
$\lambda$		-0.091	-0.148	-0.062	-0.108	0.091	-0.214	-0.180	-0.070
$\sigma$		1.417	2.239	2.013	1.975	5.861	1.832	2.060	3.139
$\rho$		-0.064	-0.066	-0.031	-0.055	0.016	-0.117	-0.087	-0.022

Table 8 – continued

		<i>Panel C: Liquidity category</i>				<i>Panel D: Duration</i>			
		<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>	<i>Pre-Crisis</i>	<i>Early Crisis</i>	<i>Full Allot.</i>	<i>Total</i>
<b><i>Main equation</i></b>									
ln(assets) <sub>m-1</sub>	ln(Eur)	0.001 (0.05)	0.020 <sup>·, [b]</sup> (0.69)	-0.033 <sup>c, [a]</sup> (-1.94)	-0.019 <sup>·, [a]</sup> (-1.20)	0.222 <sup>c, [a]</sup> (1.95)	0.301 <sup>b, [a]</sup> (2.23)	0.160 <sup>a, [a]</sup> (2.67)	0.191 <sup>a, [a]</sup> (2.99)
Equity ratio <sub>m-1</sub>	%	-0.032 <sup>a, [a]</sup> (-5.13)	-0.021 <sup>c, [a]</sup> (-1.91)	-0.010 <sup>·, [a]</sup> (-0.69)	-0.019 <sup>·, [a]</sup> (-1.53)	-0.021 <sup>·, [a]</sup> (-1.03)	-0.031 <sup>c, [a]</sup> (-1.77)	-0.012 <sup>·, [c]</sup> (-0.63)	-0.021 <sup>·, [a]</sup> (-1.31)
Write-offs & prov <sub>y-1</sub>	%	-0.047 <sup>·, [c]</sup> (-0.62)	0.017 (0.19)	0.035 <sup>·, [a]</sup> (0.85)	0.007 (0.20)	0.046 (0.14)	-0.283 <sup>·, [b]</sup> (-0.83)	0.074 <sup>·, [c]</sup> (0.49)	-0.007 (-0.05)
ROA <sub>y-1</sub>	%	-0.087 <sup>c, [a]</sup> (-1.75)	0.002 (0.10)	0.005 (0.30)	0.001 (0.05)	-0.363 <sup>b, [a]</sup> (-2.28)	-0.114 <sup>b, [a]</sup> (-2.14)	-0.029 <sup>·, [a]</sup> (-1.17)	-0.049 <sup>b, [a]</sup> (-2.24)
Constant		3.030 <sup>a, [a]</sup> (4.72)	2.508 <sup>a, [a]</sup> (3.82)	4.037 <sup>a, [a]</sup> (10.77)	3.209 <sup>a, [a]</sup> (9.25)	-0.587 (-0.22)	-1.632 <sup>·, [c]</sup> (-0.54)	-0.115 (-0.10)	0.016 (0.01)
<b><i>Selection equation: bank has positive liquidity uptake in maintenance period j</i></b>									
Positive liquidity uptake <sub>j-1</sub>		2.829 <sup>a, [a]</sup> (47.76)	2.378 <sup>a, [a]</sup> (42.20)	2.988 <sup>a, [a]</sup> (68.35)	2.824 <sup>a, [a]</sup> (81.80)	2.829 <sup>a, [a]</sup> (47.81)	2.378 <sup>a, [a]</sup> (42.16)	2.989 <sup>a, [a]</sup> (68.43)	2.824 <sup>a, [a]</sup> (81.77)
ln(assets) <sub>m-1</sub>	ln(Eur)	0.126 <sup>a, [a]</sup> (7.12)	0.133 <sup>a, [a]</sup> (7.42)	0.038 <sup>a, [a]</sup> (2.58)	0.077 <sup>a, [a]</sup> (6.84)	0.123 <sup>a, [a]</sup> (7.05)	0.133 <sup>a, [a]</sup> (7.36)	0.037 <sup>b, [a]</sup> (2.50)	0.076 <sup>a, [a]</sup> (6.73)
Equity ratio <sub>m-1</sub>	%	-0.004 (-0.51)	0.001 (0.26)	-0.008 (-1.11)	-0.004 (-0.69)	-0.004 (-0.53)	0.001 (0.24)	-0.008 (-1.15)	-0.004 (-0.77)
Write-offs & prov <sub>y-1</sub>	%	-0.112 <sup>b, [a]</sup> (-2.45)	-0.127 <sup>b, [b]</sup> (-2.40)	0.017 (0.44)	-0.056 <sup>b, [a]</sup> (-2.07)	-0.115 <sup>b, [a]</sup> (-2.48)	-0.129 <sup>b, [b]</sup> (-2.44)	0.019 (0.48)	-0.055 <sup>b, [a]</sup> (-2.08)
ROA <sub>y-1</sub>	%	-0.003 (-0.29)	-0.010 (-0.97)	-0.013 (-1.06)	-0.009 (-1.08)	-0.003 (-0.23)	-0.010 (-0.95)	-0.013 (-1.04)	-0.009 (-1.08)
Constant		-4.925 <sup>a, [a]</sup> (-11.95)	-3.996 <sup>a, [a]</sup> (-9.97)	-2.095 <sup>a, [a]</sup> (-6.16)	-3.888 <sup>a, [a]</sup> (-14.34)	-4.873 <sup>a, [a]</sup> (-11.90)	-3.995 <sup>a, [a]</sup> (-9.91)	-2.065 <sup>a, [a]</sup> (-6.09)	-3.858 <sup>a, [a]</sup> (-14.25)
atanh ρ		-0.110 <sup>a, [a]</sup> (-3.00)	-0.104 <sup>b, [a]</sup> (-2.57)	-0.072 <sup>b, [a]</sup> (-2.26)	-0.104 <sup>a, [a]</sup> (-4.45)	-0.066 <sup>b, [a]</sup> (-2.31)	-0.072 <sup>b, [a]</sup> (-2.11)	0.058 <sup>c, [b]</sup> (1.79)	-0.029 <sup>·, [b]</sup> (-1.53)
ln(σ)		-0.678 <sup>a, [a]</sup> (-16.29)	-0.479 <sup>a, [a]</sup> (-9.26)	-0.635 <sup>a, [a]</sup> (-25.50)	-0.613 <sup>a, [a]</sup> (-24.89)	0.634 <sup>a, [a]</sup> (5.74)	0.744 <sup>a, [a]</sup> (5.72)	0.377 <sup>a, [a]</sup> (9.20)	0.498 <sup>a, [a]</sup> (8.50)
# maintenance periods		18	13	23	54	18	13	23	54
# of observations		14,038	9,453	28,393	51,884	14,038	9,453	28,393	51,884
λ		-0.056	-0.064	-0.038	-0.056	-0.124	-0.151	0.085	-0.047
σ		0.508	0.619	0.530	0.542	1.885	2.104	1.458	1.645
ρ		-0.110	-0.104	-0.072	-0.104	-0.066	-0.072	0.058	-0.029