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Alessandro Calza, Julius-Benjamin Hey,
Alessandro Parrini, Stephan Sauer

Corporate loans, banks' internal risk estimates and central bank collateral: evidence from the euro area

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Abstract

We use a unique dataset of ratings for euro area corporate loans from commercial banks' internal rating-based (IRBs) systems and central banks' in-house credit assessment systems (ICASs) to investigate whether banks' IRB ratings underestimate the credit risk of their corporate loan portfolios when the latter are used as collateral in the Eurosystem's monetary policy operations. We are able to identify systematic risk underestimation by comparing the IRB ratings with those produced for the same borrowers by the ICASs. Our results show that while they are on average more conservative than ICASs for the entire population of rated corporate loans, IRBs are significantly less conservative than ICASs for those loans that are actually used as Eurosystem collateral, particularly for large loans. The less conservative estimates of risk by IRBs relative to ICASs can be partly explained by banks' liquidity constraints, but not by their degree of capitalisation. Overall, our findings suggest the existence of a collateral-related channel through which the use of IRB ratings may influence the internal estimation of risk by banks.

JEL classification: G21, G28

Keywords: Internal ratings, probability of default, banking regulation, central bank liquidity

Non-technical summary

Credit claims (mostly bank loans to the private sector and public entities) represent one of the main sources of collateral for banks participating in the Eurosystem's monetary policy credit operations. The acceptance of a credit claim as Eurosystem collateral is conditional on its compliance with a set of eligibility criteria, notably a minimum credit quality threshold. In this paper, we focus on one specific type of credit claims: bank loans to non-financial corporates (hereafter, corporate loans). In the case of corporate loans, the application of the eligibility criterion focuses on the credit quality of the borrowing firm, which is ascertained on the basis of a credit "rating" (and the associated probability of default) assigned to the firm by an accepted rating source.

The Eurosystem accepts credit ratings for corporate loans from two main categories of sources; 1) the in-house credit assessment systems (ICASs) operated by several national central banks and 2) the internal ratings-based systems (IRBs) operated by many commercial banks. While ICASs have been specifically designed to produce ratings to assess collateral eligibility, IRBs were designed to produce risk metrics for regulatory capital purposes and only subsequently used for collateral purposes. Interestingly, some recent studies (e.g. Plosser and Santos, 2014, Berg and Koziol, 2017, Behn et al, 2021) have found evidence that the estimates of credit risk by IRBs may be affected by strategic considerations about regulatory capital optimisation and that less capitalised banks may have incentives to underestimate the credit risk of their loan portfolios in order to economise on regulatory capital.

The purpose of this paper is to assess whether there may be similar evidence of credit risk underestimation by IRBs when the ratings are used to assess the eligibility of the loans as Eurosystem collateral. In particular, we investigate whether the credit risk estimates produced by a bank's IRBs may be influenced by considerations about the overall availability of collateral at the bank and/or by specific characteristics of the individual bank loans (e.g. loan size) that have an effect on their ability to be used as collateral. We are able to identify credit risk underestimation by banks by comparing the ratings internally generated by their IRBs with those produced for the same borrowers by the national central banks using their ICASs. Our approach helps to overcome well-known challenges to validate models for low-default portfolios, which are predominant in a sample of relatively high-quality eligible loans.

Using annual data on credit ratings of euro area corporate loans over the period 2014-2018, we find evidence that the IRB ratings tend to underestimate credit risk compared to the ICAS ratings when the related corporate loans are used to borrow liquidity at the Eurosystem's collateralised refinancing operations. In particular, we find that while IRB ratings appear to be on average more conservative than ICAS ratings for the entire population of corporate loans rated by both IRBs and ICASs, this relationship does no longer hold when we focus on the corporate loans that are actually used as Eurosystem collateral. In fact, the IRB ratings of the corporate loans actually used by banks in monetary policy operations tend to be less conservative than the corresponding ICAS ratings, particularly for larger corporate loans. The lower estimation of risk by IRBs relative to ICASs can be partly explained by banks' liquidity constraints, but not by their degree of capitalisation; and it appears to be driven by IRB ratings not being sufficiently conservative rather than by too conservative ICAS ratings.

Our results may provide useful information when thinking about how to improve the credit assessment framework of the Eurosystem's monetary policy operations. For instance, it could be specified that ICAS ratings should be used on a priority basis to assess eligibility of corporate loans whenever they are available. More generally, it may be beneficial to consider a cost-efficient expansion of ICASs within the Eurosystem. In addition, our findings may also be of interest for banking supervisors and commercial banks when thinking about how to improve existing statistical tests for the validation of IRBs. For instance, our empirical findings suggest that validation tests taking the size of the exposure into consideration could provide an interesting avenue for further research.

There are two caveats to the analysis that would deserve some attention in future research: first, most of our observations refer to corporate loans in three euro area countries (France, Italy and Austria); second, there are some indications that the introduction of the SSM and various regulatory and supervisory initiatives to improve IRB models may have already started to mitigate the underestimation of credit risk for mobilised collateral, with positive spill-over effects on the risk management of the monetary policy operations. Future investigations should aim to extend the geographical coverage of the sample and to assess the effect of the shift in supervisory regime using the more recent data.

1. Introduction

Credit claims represent one of the main sources of collateral for banks participating in the Eurosystem's monetary policy credit operations. At the end of 2019, the amount of credit claims (mostly bank loans to the private sector and public entities) pledged as collateral with the Eurosystem amounted to EUR 370 billion, broadly a quarter of all collateral mobilised by euro area banks. Following a number of easing measures taken during the COVID-19 crisis, the volume of credit claims used as Eurosystem collateral virtually doubled, reaching a historical high of about EUR 740 billion in June 2020 and playing an important role in enabling euro area banks to participate at the ECB's crisis-related refinancing operations.

Yet, the acceptance of credit claims as collateral in monetary policy credit operations is not automatic. The Statute of the ECB states that the Eurosystem's central banks can only provide liquidity against "adequate collateral". In order to operationalise this statutory requirement, the Eurosystem has defined a set of criteria for collateral eligibility, notably including a minimum credit quality threshold. According to this criterion, an asset can be accepted as collateral only if its credit quality equals or exceeds the minimum threshold. In the case of bank loans, the application of this criterion focuses on the credit quality of the borrower, which is ascertained on the basis of a credit "rating" assigned to each individual loan by an acceptable rating source. Because of the identification scheme used in the empirical analysis, in this paper we focus on the credit ratings of one specific type of credit claims: bank loans to non-financial corporates (hereafter, corporate loans).

The Eurosystem accepts credit ratings of corporate loans from two main categories of sources; 1) the in-house credit assessment systems (ICASs) operated by several national central banks and 2) the internal ratings-based systems (IRBs) operated by many commercial banks.[1] Both categories produce estimates of the credit quality of borrowers that can be used to assess the collateral eligibility of the relevant bank loans. However, they differ in terms of original purposes: while ICASs have been specifically designed to produce ratings for collateral purposes, IRBs were originally introduced for the calculation of banks' risk-weighted assets and, ultimately, their regulatory capital requirements. The subsequent use of IRBs for collateral purposes may be seen as a by-product of the credit assessment systems and is somehow derivative to their application for capital requirements. Nevertheless, the increasing importance of bank loans as collateral in monetary policy operations may create

1 In the specific case of bank loans to large corporates, the Eurosystem may also use ratings assigned by credit rating agencies to securities issued by these firms.

incentives for banks to incorporate considerations about collateral optimisation when operating their IRBs. If so, the measurement of the credit risk associated with one borrower may not be entirely shielded from considerations about the use of the underlying credit claim as collateral.

The hypothesis that the internal measures of credit risk by banks for regulatory purposes may be somewhat sensitive to the conditions of the same banks or characteristics of their exposures other than their "true" credit risk (e.g. loan size) is based on some evidence. Several studies have found evidence of inconsistencies in the measurement of risk across banks. For instance, European Banking Authority (2013, p.6) finds "significant differences in the capital requirements of IRB banks, especially as regards retail and corporate types of exposures" and argues that it is "very difficult to disentangle the extent to which these divergences stem from different regulatory frameworks in place across countries, from supervisory practices or from bank-specific modelling choices." The estimation and validation of credit risk models is particularly challenging for so-called low-default portfolios of loans (see, for example, Basel Committee on Banking Supervision, 2013), which are typically a source of collateral in monetary policy operations. As a result, the benchmarking of IRB ratings against alternative rating sources, such as ICASs, can be a particularly valuable exercise.

More recently, an emerging literature has shown that risk metrics produced by IRBs for capital requirement purposes may be affected by information and incentive problems. Plosser and Santos (2014) exploit differences in credit risk estimates across different banks for the same U.S. debtor of syndicated loans and find that lower capitalised banks report lower probabilities of default (PDs) by around 100 basis points, which can in turn improve the typical loan portfolio's Tier 1 capital ratio by up to one third. The sensitivity of this PD underreporting to bank's capital is found to be more pronounced for larger loans, consistent with constrained banks' desire to lower required regulatory capital. A recent paper by Berg and Koziol (2017) uses German credit register data to find that 95% of the large PD variation across IRB banks is idiosyncratic. Nevertheless, these authors observe some evidence of lower PDs being reported by lower capitalised banks. An interesting paper by Behn et al. (2021) exploits the staggered, portfolio-specific regulatory authorisation for the transition from the standardised approach to the IRB approach in Germany and find interesting evidence of regulatory arbitrage: once IRB models are authorised for capital requirements purposes, their ratings become less conservative than those of the internal models used by banks only for non-regulatory purposes.[2] In addition, these authors find that the incentives to underreport PDs are particularly pronounced for banks relatively undercapitalised.[3]

The purpose of this paper is to investigate whether there is analogous evidence of credit risk underestimation by IRBs when the ratings of the bank loans are used for a different public policy purpose, namely to assess the eligibility of the loans as collateral in the ECB's monetary policy operations. In particular, we investigate whether the credit risk estimates produced by a bank's IRBs may be influenced by the overall availability of collateral at the bank and/or by specific characteristics of the bank's loans that have an effect on their ability to be used as collateral. We are able to identify credit risk underestimation by banks by comparing the ratings internally generated by their IRBs with those produced for the same borrowers by the national central banks using their ICASs. Since central banks are independent public entities authorities bound by policy objectives and the prudent management of public funds, we can exclude that ICASs have any commercial interest in assigning excessively favourable ratings to specific entities. This difference in perspectives between central banks and commercial banks (i.e. policy versus commercial interests) allows identifying any systematic behavioural differences in the assignment of ratings between ICASs and IRBs and may thus reveal any evidence of strategic use of their IRBs by banks when rating bank loans mobilised as collateral.

To preview our results, over the period 2014-2018 we find evidence of systematic behavioural differences between IRBs and ICASs when assigning ratings to bank loans to corporates that are actually used as collateral in the Eurosystem's monetary policy operations. Interestingly, when we first compare IRB and ICAS ratings across firms for the entire population of corporate loans eligible as collateral that are rated by an ICAS and at least one IRB, we show that IRBs are on average more conservative than ICASs. However, when we focus the analysis on the ratings of the loans that are actually used as collateral, we find that the IRB ratings tend to be less conservative than the corresponding ICAS ratings. In addition, we provide empirical evidence that the lower degree of conservativeness of IRBs compared to ICASs is more pronounced for relatively larger bank loans, which are particularly relevant for collateral exposures. Furthermore, we show that this result is unlikely to be driven by ICAS being too conservative when assessing the credit risk associated with

2 In addition, Mariathasan and Merrouche (2014) found, using aggregate data that for several international banks risk-weighted assets become lower once regulatory approval for IRB use is granted.

3 Begley et al. (2015) consider these incentive problems in the context of banks' internal market risk models.

the collateral. As regards the characteristics of banks, we find that the IRBs of banks that are likelier to be liquidity-constrained tend to be relatively less conservative than ICAS when assigning ratings to corporate loans. By contrast, the degree of capitalisation of banks does not seem to have explanatory power over the difference between ratings of IRBs and ICASs for bank loans that are used as collateral. The latter result is important since it suggests that our empirical findings may indicate an additional collateral-related channel at work (independent of the regulatory capital channel in the earlier-mentioned literature) through which the internal credit quality rating processes of banks may be affected by factors related to the conditions of the banks themselves or characteristics of their exposures other than "true" credit risk.

2. Role of IRBs and ICASs in the Eurosystem monetary policy operations

The Eurosystem specifies a wide range of assets as potentially eligible collateral in its refinancing operations. These assets include bonds issued by governments and other public authorities, marketable securities issued by the private sector and loans to public authorities and non-financial corporations granted by banks.[4] As mentioned earlier, all of these assets must meet the ECB statutory requirement of "adequate collateral". In order to operationalise this requirement, the Eurosystem has defined a set of rules forming the so-called Eurosystem Credit Assessment Framework (ECAF). According to these rules, an asset belonging to an eligible category can actually be accepted as collateral only if its credit quality equals or exceeds a minimum credit quality threshold. Furthermore, the credit quality influences the valuation haircuts applied to the loan value.

In order to ascertain the credit quality of an asset, the Eurosystem uses different sources of credit assessments. For marketable securities, the assessment is usually based on ratings from a small number of "ECB-accepted" credit rating agencies with pan-European coverage. For bank loans, the assessment focuses on the credit quality of the borrower. While ratings from the credit rating agencies are usually available to assess loans to public authorities, this is not the case for the large majority of loans to non-financial corporations. In fact, the rating agencies accepted by the ECB typically rate only a few hundred large firms in the euro area.

[4] In some countries, national central banks accept loans to private individuals (mainly pools of residential mortgages) as part of the so-called "additional credit claims" frameworks (see Tamura and Tabakis, 2013). These are frameworks introduced during the crisis as part of a temporary expansion of the collateral framework. In the empirical part of this paper, we focus only on loans to firms accepted as part of the permanent collateral framework.

Therefore, for the vast majority of loans to non-financial corporations, the Eurosystem relies on two alternative sources of credit assessments: (1) ICASs operated by the national central banks; and (2) banks' own IRBs.

ICASs are credit assessment systems developed by central banks that assign internal ratings to non-financial corporations. During the period under consideration (2014-2018), there were eight central banks within the Eurosystem that operated ICASs: National Bank of Belgium, Deutsche Bundesbank, Banco de España, Banque de France, Banca d'Italia, Oesterreichische Nationalbank, Banco de Portugal and Banka Slovenija. Some of these national central banks operated an ICAS even before the creation of the euro area in 1999, while other central banks have developed them in recent years as the relative importance of bank loans as collateral in Eurosystem credit operations has increased. The ICASs from different national central banks follow common principles, standards and procedures that ensure the integrity and independence of their internal assessments. ICAS ratings are non-public and used primarily for the assessment of collateral, but central banks can use them also for various analytical purposes (e.g. financial stability analysis, benchmarking of IRB ratings, etc.).[5] The number of borrowers rated by ICASs ranges from below 100 in Spain to more than 100,000 in France (and each of these borrowers may have potentially received more than one bank loan from different banks). From the perspective of central banks, the ICASs present the two-fold advantage of: 1) helping them to reduce the reliance on external ratings in line with the principles agreed at the G20 level[6]; and 2) supporting the implementation of monetary policy by allowing banks without an IRB system to mobilise loans to non-financial corporations as collateral.

While ICAS are specifically set up to assess collateral eligibility, IRBs have been designed for the calculation of risk-weighted exposures for capital requirements purposes. However, IRBs that are authorised by the relevant supervisor for capital requirements purposes and comply with additional reporting requirements set by the Eurosystem can also be used as credit assessment source for the collateral used in monetary policy operations. Additional reporting requirements allow to conduct due diligence on the IRB ratings that are specifically used for collateral purposes, as the perimeter of bank loans used as collateral differs from that for capital requirements purposes. For example, only the subset of bank loans above the

5 Only Banque de France's ICAS can be also used by banks for capital requirements purposes.

6 See Financial Stability Board (2010).

ECB's minimum credit quality threshold is eligible as collateral, whereas the supervisor focuses on the whole portfolio of bank loans.

If both types of systems are available, a bank can choose to use either its own IRB or the domestic ICAS as its "primary source" of assessment for non-financial corporations for collateral purposes, with the other system acting as a "secondary source". Importantly, once the choice is made, it applies by default to all the borrowers assessed by the system. This means that whenever a rating from the selected primary source is available for a given non-financial corporation, the bank must use it by default and is not allowed to arbitrarily select a different (and possibly better) rating from the secondary source. The secondary source can be used only if there is no available rating for a specific company from the primary source.[7] The bank can also not switch to a different primary source for at least one year after it has chosen its primary source.

The choice of a system as a primary source may depend on different factors. For instance, a bank may prefer using its own IRB because of considerations about the scope of the system (if the relevant NCB operates an ICAS with relatively limited coverage of firms) or if it provides relatively better ratings than the alternative credit assessment system.[8] The Eurosystem aims to ensure comparability *on average* of the systems through the mapping of their scores onto a harmonised rating scale and the regular monitoring of the ex-post performance of the systems. However, banks may be able to exploit distributional differences in ratings at individual debtor level across systems. For instance, one system may produce comparatively better ratings for specific categories of debtors (e.g. large debtors).

Differences in ratings across credit assessment sources are relevant because they may yield benefits to banks in terms of eligibility and/or haircuts. For instance, the Eurosystem specifies a minimum threshold for collateral eligibility (so-called Credit Quality Step 3, equivalent to a one-year PD up to 0.4%). For bank loans that are borderline in terms of credit quality, rating differentials across credit assessment sources may make the difference between eligibility and exclusion.[9] Rating differentials may also affect the haircuts applied to eligible bank loans

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7 Since the analysis in this paper focuses on the comparison of ICAS and IRB ratings for the same firm, usually only the rating from the primary source is used for the mobilisation of the credit claim in this paper.

8 A-priori, counterparties only know the list of eligible obligors according to the respective ICAS assessment. However, they receive from the NCB's collateral management a statement reporting the collateral value after haircut for each mobilised credit claim. Given that the counterparties know the outstanding amount, maturity and interest rate type of mobilised credit claims, they infer the 'rating quality step' ex-post.

9 In some countries, national central banks may accept loans of lower credit quality as part of their crisis-related "additional credit claims" frameworks with higher haircuts (Tamura and Tabakis, 2013).

by the Eurosystem. The ECB specifies two different sets of haircuts depending on credit quality: lower haircuts for assets in Credit Quality Steps 1 and 2 (i.e. with a one-year probability of default up to 0.1%) and higher ones for assets in Credit Quality Step 3. The difference in haircuts between two loans with the same coupon structure that are in different haircut buckets because of credit quality difference can be very significant and range between 7 and 18 percentage points for fixed rate claims and between 7 and 23.5 percentage points for variable rate claims, depending on the maturity. Therefore, there may be incentives to choose a specific credit assessment system strategically if this is believed to produce better ratings on average for all borrowers or for a specific category of borrowers of particular interest for collateral purposes. In the empirical approach section, we will explore this hypothesis.

3. Data and sample summary

This paper uses data on (i) PDs collected from IRBs and ICASs;[10] (ii) assets used to collateralise Eurosystem credit operations; and (iii) banks' capital ratios and liquidity ratios. Our sample covers yearly data between 2014 and 2018. It thus covers the setup of the Single Supervisory Mechanism (SSM) in late 2014, when the ECB took over the responsibility for the supervision of "significant institutions" in the euro area after conducting a comprehensive asset quality review of the banks (though our sample also includes "less significant institutions" that are directly supervised by national authorities). Over the period considered the provision of data on individual firms to the Eurosystem was mandatory for ICASs and IRBs.

As part of an annual exercise, all ICAS and IRBs are subject to a due diligence and performance monitoring process. For this purpose, they are required to submit annual data on the entire universe of borrowers assessed by the systems that have received loans which are eligible for use as collateral in Eurosystem monetary policy operations. Importantly, we restrict our data to non-financial firms that are simultaneously rated by an ICAS and at least one IRB system to allow for a direct comparison between the PDs from the two different categories of rating sources. PDs are estimates of the probability of default of a debtor over a one-year horizon. For non-retail debtors, the PD under the Capital Requirements Regulation

[10] All empirical results are based on PDs, while we use the terms "ratings" and "PDs" interchangeably throughout the paper. Many credit assessment systems, in particular those including expert assessments like the ICAS, produce ordinal ratings that are then mapped to cardinal PDs. Purely statistical credit assessment systems can also provide PDs directly.

is a firm-specific parameter, i.e. it should reflect the creditworthiness of the firm abstracting from the recovery rate (which drives instead the loss given default) or the exposure amount. Thus, in principle, all IRBs from banks that are providing loans to a given firm should arrive to a similar PD, regardless of the size of the loan or the specific contractual agreements with the firm. ICAS also provide PDs exclusively on a debtor-basis.

Data for ICAS and IRB systems comprises PDs both at the beginning and at the end of the year. In our main empirical exercise, we use end-of-year PDs to benefit from greater rating variability and beginning-of-year data only for robustness analyses. The reason is that the beginning-of-year data are by definition bounded by the ex-ante eligibility threshold (unlike end-of-the-year PDs that may also refer to assets that have lost eligibility throughout the year). The focus of this paper is, however, on portfolios with high credit quality debtors (see Annex A2.3 for an analysis).[11]

In the empirical analysis, we consider first the full sample of observations for all eligible loans from borrowers simultaneously rated by an ICAS and at least one IRB system, regardless of whether or not banks actually mobilise these loans as collateral with the central banks (labelled *Panel A*).[12] We then construct a narrower set of data (*Panel B)* by focusing only on those bank loans that are *actually mobilised* as collateral and that are simultaneously rated by an ICAS and at least one IRB system. For this panel of mobilised bank loans, we are able to combine information on the credit assessment source selected by the bank as its primary source with data on the collateral value after haircuts of those bank loans. While restricting the sample to firms whose bank loans are mobilised as collateral reduces the sample compared to *Panel A,* the distribution is more evenly distributed mostly across three countries (see Table 1).

As a next step, we add further information at the bank level in order to exploit bank characteristics that may change over time. More precisely, *Panel C* adds as bank controls: (i) the ratio between the size of central bank liquidity provided to the bank and the total collateral mobilised by the banks, and (ii) the banks' Common Equity Tier 1 (CET1) capital ratios. As information on CET1 ratios[13] is not available for some IRB banks (particularly, for those not supervised by the ECB), the sample size of Panel C is marginally smaller (see

[11] Interestingly, Behn et al. (2021) note that the incentive for underreporting PDs by banks is stronger for these high credit-quality firms given the non-linearity of the relationship between PDs and risk weighted assets.

[12] We drop entities for which either an IRB system or an ICAS reported a PD=100% (less than 1% of observations) to focus on performing loans which could be used as collateral in the context of monetary policy operations.

[13] The CET1 ratio is based on data at 'consolidated' level when available, or otherwise, at 'solo' level.

Table 1). Finally, we build a dataset (labelled *Panel D*) including loans to firms that are rated by at least four IRBs. Naturally, this narrows the panel down since there are fewer countries in which more IRB banks rate the same (relatively larger) debtors.[14] This panel will be used to conduct robustness checks in order to assess the reliability of the ICAS ratings as benchmarks against which to assess the IRB ratings. Indeed, our empirical strategy assumes that the ICAS ratings provide a reliable benchmark because of the "neutrality" of central banks when rating the bank loans. However, this strategy would be invalidated if ICAS proved to be excessively conservative due to low tolerance or other factors. As explained in Section 4, the use of an alternative benchmark based on IRB ratings from other banks for the same borrowers allows us to cross-check whether ICAS ratings are too conservative.

Overall, the dataset comprises seven ICASs and 58 IRB banks.[15] Table 1 below shows the distribution of firms by national central bank for our four datasets (*Panel A, B, C D*). All relevant variables as well as the specific sample characteristics of *Panels A-D* are summarised in Table A1 and Table A2 of Annex 1.

Table 1: Distribution of firms in Panel A - D between 2014 and 2018

(firm-year observations by NCB)

NCB	Number of (#) firms rated by an ICAS	# firms rated by at least 1 IRB	Panel A	Panel B	Panel C	Panel D
			# firms rated by ICAS and at least 1 IRB	# mobilised firms rated by ICAS and at least 1 IRB	# firms in Panel B of banks with known CET1 ratio	# mobilised firms rated by at least 4 IRBs
AT	12,943	172,635	9,946	3,812	3,664	652
BE	1,290	361,004	502	113	91	12
DE	53,954	9,718	939	235	104	-
FR	689,935	1,994,854	190,243	7,599	6,982	351
IT	5,763	2,445,245	23,815	4,915	4,700	29,891
PT	1,058	331,702	971	216	216	-
SI	1,904	405	77	6	6	-
Total	**767,275**	**5,348,622**	**226,493**	**16,896**	**15,763**	**30,906**

Note: AT denotes Austria, BE Belgium, DE Germany, FR France, IT Italy, PT Portugal and SI Slovenia.

[14] While Panels B and C are relatively evenly distributed mostly across three countries (Austria, France and Italy), Panel D uses mainly Italian data.

[15] 7 ICASs and 33 IRBs provided data from 2014. The Portuguese ICAS was accepted in 2016, thus providing data only from 2015 to 2018. The remaining 25 IRBs provided data only for the subset of years for which the respective bank requested the IRB's use for monetary policy purposes. In the absence of IRB information from Spanish counterparties, the Spanish ICAS is not included in our analysis.

4. Empirical approach

In our empirical analysis, we aim to investigate whether there are systematic differences between the PDs provided by banks' IRB models and those from the ICASs operated by central banks and, if so, whether there are bank- or loan-related characteristics that may explain those differences. Our empirical strategy relies on the use of the PDs provided by ICASs as a "neutral" benchmark for the credit risk measurement of each firm. Since central banks are public policy authorities and provide the output of their ICASs to all banks in their countries, the ICAS PDs should not suffer from any systematic bias when assessing the credit quality of firms in the portfolio of individual banks. Therefore, the comparison of the IRB PDs with the ICAS PDs for the same firms allows identifying the potential underestimation of credit risk by IRBs relative to the benchmark.

We begin our analysis by testing whether there is a systematic difference between the PDs produced by IRBs and ICASs for the full sample of eligible loans (*Panel A*) by estimating the following equation:

$$\log\left(PD_{IRB_{ijt}}/PD_{ICAS_{ikt}}\right) = FE + \varepsilon_{ijt} \quad (1)$$

where *i* denotes the individual firm, *j* denotes the individual IRB bank, *k* denotes the individual ICAS, and *t* denotes time (year). The use of the log ratio between PD_{IRB} and PD_{ICAS} addresses the non-linearity in the difference between PDs, and is in line with the relevant empirical literature.[16] We estimate equation (1) using different specifications: first, with time fixed effects to identify potential business cycle effects or structural changes in the supervisory framework for IRBs; then with firm fixed effects to control for unobserved characteristics of individual firms.

We then repeat the exercise for the portfolios of bank loans mobilised as collateral in Eurosystem credit operations. We are interested in investigating whether any potential difference between PD_{ICAS} and PD_{IRB} identified for the full portfolio of bank loans is confirmed in the case of bank loans specifically mobilised as collateral, i.e. in those cases for which the PD directly matters for monetary policy operations. For this purpose, we restrict our dataset to the PDs of firms whose bank loans are used as collateral in monetary policy operations (*Panel B*) and estimate:

$$\log\left(PD_{IRB_{ijt}}/PD_{ICAS_{ikt}}\right) = \delta \cdot D_{ijt} + FE + \varepsilon_{ijt} \quad (2)$$

[16] E.g. Behn et al. (2021) and Berg and Koziol (2017). The results presented in Section 5 are robust to using the absolute difference between the IRB PD and the ICAS PD.

where the dummy D_{ijt} indicates the bank's primary source.[17] Thus, D_{ijt} equals 1 if bank *j* uses its IRB PD for the mobilisation of its loan to firm *i* at time *t*, and 0 when ICAS *k* is instead used for the mobilisation of the same loan.

We use different specifications of fixed effects to ensure the robustness of our estimates. We apply firm fixed effects in each specification to account for variation within the same firm. The second specification adds time fixed effects to control for euro area business cycle conditions. The third specification includes country- time interactions to control for country-specific business cycle conditions. Finally, we use interactions between firm and time fixed effects to control for variation across IRB banks *within the same firm* and *the same year.* We apply these four specifications of fixed effects also in all remaining estimations.[18]

Next, we are interested in investigating whether the size of the mobilised bank loans, which can be seen as a proxy for the exposure of bank *j* to firm *i*, can explain the difference between PD_{IRB} and PD_{ICAS}. The size of the mobilised loans determines the amount of central bank liquidity that the bank can receive by mobilising a specific loan and, more generally, the relevance of the loan for the bank's balance sheet. We still focus on the subset of IRB PDs of loans mobilised as collateral with the Eurosystem and estimate the following equation:

$$\log\left(PD_{IRB_{ijt}}/PD_{ICAS_{ikt}}\right) = \delta \cdot D_{ijt} + \alpha \cdot CVAH_{ijt} \cdot D_{ijt} + FE + \varepsilon_{ijt} \quad (3)$$

where $CVAH_{ijt}$ denotes the logarithm of the collateral value after haircut of loans to firm *i* that are mobilised as collateral by bank *j* at time *t*.

It is important to recall that while IRB systems are used to assess the credit quality of loans as collateral, they have been originally developed for regulatory capital purposes and, as mentioned in the introduction, some authors have found evidence that weaker banks may underreport the credit risk associated with their loan portfolios in order to minimise capital requirements. Therefore, it is possible that any identified PD gap between IRBs and ICASs may be a by-product of banks' strategic use of PDs from IRBs for regulatory capital purposes rather than being driven by liquidity constraints. In order to investigate this hypothesis, we estimate the following equation:

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[17] See Annex A2.2 for a more detailed review of the difference between PDs from IRBs and ICASs.

[18] Note that including dummy D_{ijt} prevents the inclusion of bank (- time) fixed effects as banks consistently use either IRB or ICAS PDs to mobilise collateral in a single year. Only under very exceptional operational circumstances both of them are used with the same year; such cases have been excluded.

$$\log\left(PD_{IRB_{ijt}}/PD_{ICAS_{ikt}}\right) = \delta \cdot D_{ijt} + \alpha \cdot CVAH_{ijt} \cdot D_{ijt} + \beta \cdot L_{jt} \cdot D_{ijt} + \gamma \cdot C_{jt} \cdot D_{ijt} + FE + \varepsilon_{ijt} \quad (4)$$

where L_{jt} denotes the ratio of central bank liquidity provided to bank j relative to the total collateral after haircut[19] mobilised by bank *j*, which can be a proxy of how liquidity-constrained bank *j* is, and control for the role of capital requirements by including C_{jt}, the Common Equity Tier 1 ratio of bank *j* at time *t*.

As mentioned earlier, our testing strategy is based on the assumption that ICAS ratings provide a reliable benchmark against which to assess IRB PDs because of the lack of strategic or commercial interests of central banks when assessing bank loans. Therefore, a negative gap between PD_{IRB} and PD_{ICAS} for a loan portfolio is indicative of credit risk underestimation by insufficiently conservative IRBs. However, a similar gap may also emerge under the hypothesis of unbiased IRB PDs if the ICAS is excessively conservative. In order to check the robustness of our estimates and to differentiate between the alternative explanations of insufficiently conservative IRB PDs versus excessively conservative ICAS PDs, we consider an alternative PD benchmark using the average IRB PD assigned to the same debtor by different IRB banks (similar to Plosser and Santos (2014)), instead of the ICAS PD[20]. More precisely, if at least three banks - other than bank *j* - assign a PD_{IRB} to the individual firm *i*, we calculate the average IRB PD excluding bank *j* that we denote $avg_{-j}(PD_{IRB_{i-jt}})$. If the results obtained using the ICAS PDs as a benchmark were confirmed also with the benchmark based on the average of the PDs produced by other IRBs, we would have additional evidence in support of the hypothesis of insufficiently conservative IRBs (as opposed to excessively conservative ICASs).

We therefore estimate Equations (2'), (3') and (4') by replacing PD_{ICAS} with this alternative benchmark; for instance, Equation (4') is specified as follows:

$$\log\left(PD_{IRB_{ijt}}/avg_{-j}\left(PD_{IRB_{i-jt}}\right)\right) = \delta \cdot D_{ijt} + \alpha \cdot CVAH_{ijt} \cdot D_{ijt} + \beta \cdot L_{jt} \cdot D_{ijt} + \gamma \cdot C_{jt} \cdot D_{ijt} + FE + \varepsilon_{ijt} \quad (4')$$

The error term in the above equations can potentially exhibit auto-correlation if observations in two subsequent years for the same firm are not independent. A standard OLS estimator –

[19] This includes not only bank loans, but also marketable assets (such as government bonds, covered bonds or asset-backed securities).

[20] Several authors find evidence of inconsistencies in internal risk metrics for the same borrowers across banks (e.g. Berg and Koziol, 2017, Carey, 2002, Firestone and Rezende, 2013, and Jacobson et al., 2006).

which relies on an *i.i.d.* assumption for the error term – would yield biased standard errors. Therefore, we cluster the standard errors by firm in all the estimations.[21]

In addition, we conduct a robustness check to assess whether the results are stable over time, as the institutional changes related to the introduction of the SSM in 2014 and the launch of a major supervisory review of IRBs in 2016 (the "Targeted Review of Internal Models", see ECB, 2021) might have induced breaks in the credit risk assessments by banks.[22] Consistent with this hypothesis, an analysis of the performance of IRB PDs relative to realised default rates over the sample period shows that ex-ante IRB PDs tended to (significantly) under-predict actual defaults in the first three years of the sample (2014-2016) and to over-predict them in 2017 and 2018 though to a lesser extent (see Table A3 in Annex 2). We thus split the sample period into two sub- samples and estimate equations (2) to (4) separately before testing for equality of the estimated coefficients across the sub-samples.

Finally, we conduct a robustness check on the $CVAH_{ijt}$ in equations (3) and (4) using both the ICAS PD benchmark and the average IRB PD benchmark. As mentioned, we use the collateral value after valuation haircuts applied by the central bank instead of the nominal outstanding amount because it better captures the relevance of the loan for monetary policy operations. Moreover, it takes account of information on certain characteristics of the loans (e.g. residual maturity, coupon type, etc.) that influence the relevant haircut. However, because the applied haircut partially depends not only on the maturity and the coupon type of the loan, but also on the PD_{it} provided by the selected primary source, $CVAH_{ijt}$ is not fully exogenous. We thus test the robustness of our results by using the lagged $CVAH_{ijt-1}$ as an instrumental variable for $CVAH_{ijt}$ and re-estimating equations (3) and (4), as well as (3') and (4'), using the two-stage least squares estimator.[23]

[21] In line with the literature, e.g. Plosser and Santos (2014) and Berg and Koziol (2017). Importantly, obtaining the standard errors via bootstrapping does not change the significance of the coefficients. To mitigate the effect of extreme values, the top and bottom 1% of the yearly log PD ratios are winsorised in all the results presented (as in Berg and Koziol (2017)). The winsorising procedure does not affect the final results.

[22] The "Targeted Review of Internal Models" by the ECB Banking Supervision resulted in a 12% increase, or about €275 billion, of risk-weighted assets covered by the investigated models (see ECB, 2021).

[23] No potential endogeneity issue arises for equation (2) since it does not include $CVAH_{ijt}$.

5. Results

The estimate of equation (1) using *Panel A* (i.e. the full portfolios of eligible loans) shows that the coefficients of the log-differences in PDs are positive and statistically significantly across the five available years, indicating that the PDs from IRBs are consistently higher than those derived from ICASs (see Table 2, column 1). The signs of the coefficients are robust to the introduction of firm fixed effects (see column 2). Overall, the results suggest that banks' IRB models assign, on average, more conservative PDs to corporate loans than the ICAS models of central banks representing a neutral benchmark. From a policy perspective, these preliminary results appear rather reassuring with regard to the use of bank's IRB models for regulatory purposes.

Table 2: Estimation of Equation (1)

	(1) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	(2) $\log \frac{PD_{IRB}}{PD_{ICAS}}$
Year = 2014	0.709***	0.548***
	(0.008)	(0.007)
Year = 2015	0.887***	0.798***
	(0.011)	(0.008)
Year = 2016	0.760***	0.848***
	(0.010)	(0.009)
Year = 2017	0.794***	0.828***
	(0.010)	(0.010)
Year = 2018	0.885***	0.951***
	(0.010)	(0.010)
Firm FE	No	Yes
Observations	226493	226493
Adj. R-squared	0.002	0.582

Regression results of the logarithm of the ratio between IRB PDs and ICAS PDs (dependent variable) and year dummies. The sample used is "Panel A". Column (1) is estimated with pooled OLS; column (2) includes firm fixed effects. Standard errors are reported in parentheses and are adjusted in column (2) for clustering at the firm level. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

However, the picture is reversed when we restrict the analysis to the sample of firms whose loans are mobilised by banks as collateral (Panel B). The estimation of equation (2) shows a statistically significant negative gap between IRB PDs and ICAS PDs (see first column of Table 3), indicating systematic risk underestimation by IRBs relative to ICASs. The results indicate that when a bank uses firm *i*'s debt as collateral, the log-difference between its IRB PD and the ICAS PD is -0.407, i.e. IRB

PDs are one third lower than ICAS PDs. The negative sign of the coefficient of the (primary) source dummy is robust to different specifications of fixed effects (see Table A5 in Annex 3).

Table 3: Results of Equation (2) to (4) with firm-year fixed effects

	Equation (2) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (3) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (4) $\log \frac{PD_{IRB}}{PD_{ICAS}}$
Source = IRB	-0.407***	-0.331***	0.646***
	(0.054)	(0.055)	(0.129)
Source = ICAS × log CVAH		-0.044***	-0.010
		(0.015)	(0.016)
Source = IRB × log CVAH		-0.200***	-0.193***
		(0.020)	(0.020)
Source = ICAS × Liquidity utilization			0.392***
			(0.077)
Source = IRB × Liquidity utilization			-1.309***
			(0.118)
Source = ICAS × CET1 ratio			4.367***
			(0.571)
Source = IRB × CET1 ratio			3.545***
			(0.364)
Firm x Year FE	Yes	Yes	Yes
Observations	16896	16896	15763
Adj. R-squared	0.725	0.737	0.752

Regression results of Equation (2), (3), and (4). For equations (2) to (4), the dependent variable is the logarithm of the ratio between IRB PD and ICAS PD. Equation (2) and (3) use "Panel B", Equation (4) uses "Panel C". The dummy "Source = IRB" is equal to 1 if a bank uses its IRB PD for a firm for the mobilisation of its loan to that firm, and equals 0 when an ICAS is instead used for the mobilisation of a loan to the same firm. Log CVAH denotes the logarithm of the collateral value after haircut of loans to a firm that are mobilised as collateral by each bank. "Liquidity utilisation" denotes the ratio of central bank liquidity provided to a bank relative to the total collateral after haircut mobilised by the same bank. CET1 ratio is the Tier 1 capital ratio of each bank. All results are estimated using firm-year fixed effects. Robust standard errors adjusted for clustering at the firm level are reported in parentheses. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

We consider potential explanatory variables for the underestimation of banks' IRB PDs relative to ICAS PDs. We start by investigating the role of the size of the corporate loan used by the bank as collateral with the Eurosystem. Our estimates of equation (3) suggest that the larger the collateral value of the loan (*CVAH*), the larger the credit risk underestimation of IRBs relative to ICASs, when the loan's credit risk is assessed on the basis of the banks' own internal models (see column 2 of Table 3). This is evidenced by the negative and significant coefficient of the interaction between the dummy and collateral size when the dummy equals 1 (i.e. when the loan mobilised as collateral is rated by the bank's own IRB). While it may be plausible to assume that larger loans are on average less risky[24] (because of the likely correlation with the size of borrowers), it should be recalled that the dependent variable is specified in terms of deviations from a neutral PD benchmark, which should also reflect the effect of the borrower's characteristics on its creditworthiness. More precisely, when the IRB system is chosen as primary source, an increase in the loan exposure by one standard deviation implies, ceteris paribus, a drop in the IRB PD by 27% relative to the corresponding ICAS PD.[25] These results are robust to different specifications of fixed effects (see Table A6 in Annex 3).[26]

In addition, we empirically explore whether the measurement of credit risk by banks may be to some extent influenced by their own conditions (as opposed to being exclusively focused on the borrower's creditworthiness). In particular, we investigate whether banks with liquidity constraints and/or weaker capital positions may have additional incentives to underreport their internal PDs relative to the benchmark. Therefore, we use *Panel C* and analyse the possible role of these two bank-related characteristics by interacting them with the source dummy and estimating equation (4).[27]

The results (see column 3 of Table 3) indicate that, for banks that use IRB PDs as their primary credit assessment source in the monetary policy operations, an increase in the liquidity utilisation ratio (which is a proxy for collateral constraints)[28] by one standard deviation results in a decrease in IRB PDs by one fourth compared to the ICAS PDs for the same firms. In contrast, when ICAS PDs are used as the primary source, a smaller (and positive) relationship is found between IRB PDs and the liquidity utilisation ratio. Therefore, our estimates provide evidence that liquidity and collateral constraints may explain to some extent the underestimation of IRB PDs relative to the benchmark when banks use their own internal rating systems. Importantly, the introduction of bank's liquidity utilisation rate does

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24 See e.g. Berger and Udell (1990) who present evidence for the link between loan size and credit risk.

25 $PD_{IRB_{ijt}} = PD_{ICAS_{ikt}} * exp(-0.2 * 1.59)$, where 1.59 is the standard deviation of $\log(\mathrm{CVAH})$. The overall effect, when the IRB PD is used to mobilise collateral, is a PD almost halved compared to an ICAS PD.

26 Figure A2 of Annex A2.2 highlights that taking into account the size of the banks' exposures is crucial in order to understand if a model performs poorly for very small or very large debtors. In conjunction with the results from Annex A2.1, it confirms that conventional statistical models do not capture the underestimation of credit risk of these sub-portfolios.

27 Other controls at bank level, such as total assets or return on equity, proved not significant suggesting that they are already captured by the inclusion of the bank's fixed effects.

28 However, the level of the liquidity rate may depend on the bank's business model or liquidity management practices. Future research could aim at separating the two effects, for example by looking at changes of the liquidity utilisation rate rather than levels, as a proxy for collateral constraints.

not change the effect of the collateral size on the dependent variable, which is again significant and negative when the IRBs are used as a primary source. This result is robust to several re-specifications of the fixed effects (see Annex 3, Table A7).

In line with the literature, we find evidence of sensitivity of IRB PDs to the degree of capitalisation of banks, with the coefficients of the CET1 ratio being statistically significant and positive. However, we do not find evidence that banks' capitalisation plays a specific role on the underestimation of PD IRBs relative to the benchmark when banks use their own IRBs for credit risk measurement. In fact, the positive relationship between the capital ratio and the dependent variable holds independently of whether IRBs or ICASs are used as primary sources for the credit risk assessment of collateral, as the IRB interaction coefficient of 3.545 is not statistically different from the ICAS interaction coefficient of 4.367 in column (3) of Table 3. In more detail, in both cases, a 1-percentage point lower CET1 ratio implies an average IRB PD reduced by a factor between 2.4% and 4.5% relative to the benchmark (see Table A7 in Annex 3).

The interpretation of the coefficient of the CET1 ratio may give rise to some endogeneity concerns regarding the causal link between banks' capitalisation and PDs. It could be argued that the estimated relationship does not reflect the incentives for poorly capitalised banks to underreport their PD estimates, but rather that banks with less risky portfolios may have lower CET1 ratios ('reverse causality'). However, lower (higher) IRB PDs lead to lower (higher) risk-weighted assets (and, everything else equal, higher (lower) CET1 ratios) in a mechanical way, according to the IRB formula for risk-weighted assets in the Basel approach. Therefore, the coefficients of the CET1 ratio in equation (4) should be downward (not upward) biased. Moreover, the inclusion of the source dummy (which is similar to using banks' fixed effects as explained in Section 4) should avoid that the positive correlation between the PDs and the CET1 ratio is driven by unobserved characteristics of banks. Finally, we notice that the standalone primary source dummy D_{ijt} becomes positive in equation (4) in Table 3; this implies that if IRB PDs are used to mobilise collateral and everything else is equal, IRB PDs are lower than ICAS PDs only if the collateral mobilised is sufficiently large.[29]

[29] In view of the estimations of equation (4), for an IRB with average CET1 ratio and utilisation rate (see Table A2, Annex 1) a back-of-the-envelope calculation shows that the collateral value must be in the magnitude of EUR 10 million or higher for ICAS PDs to exceed IRB PDs. The average collateral value in Panel C is EUR 4.67 million with a standard deviation of EUR 14.6 million.

As a robustness check and to test the hypothesis that our results may be driven by too high ICAS PDs rather than too low IRB PDs, we use the average IRB PD of other IRB banks in the sample as a benchmark instead of the ICAS PD. We exploit the characteristics of Panel D and estimate equations (2') to (4'). We compare, in each sample year, the PD assigned by bank *j* to firm *i* with the average PD assigned to the same firm by (at least three) other IRB banks. Using the same specifications and banks' controls, our previous results are all confirmed (see Table 4). Banks that use their IRB PDs for the mobilisation of collateral underreport their PDs also vis-a-vis this alternative benchmark. These estimates support the hypothesis that our results are driven by insufficiently conservative IRB PDs used for the mobilisation of collateral, rather than too conservative ICAS PDs. Furthermore, similarly to what we find above, the underestimation of IRB PDs is more pronounced for banks with more liquidity or collateral constraints as captured by the liquidity utilisation ratio.

Table 4: Results for average IRB PD of other IRB banks as benchmark PD with firm-year fixed effects

	Equation (2') $\log \frac{PD_{IRB}}{PD_{IRB}^{avg}}$	Equation (3') $\log \frac{PD_{IRB}}{PD_{IRB}^{avg}}$	Equation (4') $\log \frac{PD_{IRB}}{PD_{IRB}^{avg}}$
Source = IRB	-0.815***	-0.694***	0.755***
	(0.083)	(0.085)	(0.212)
Source = ICAS × log CVAH		-0.061**	-0.002
		(0.026)	(0.027)
Source = IRB × log CVAH		-0.263***	-0.264***
		(0.013)	(0.013)
Source = ICAS × Liquidity utilization			0.451***
			(0.114)
Source = IRB × Liquidity utilization			-0.979***
			(0.072)
Source = ICAS × CET1 ratio			6.875***
			(0.946)
Source = IRB × CET1 ratio			4.227***
			(0.222)
Firm x Year FE	Yes	Yes	Yes
Observations	30906	30906	30011
Adj. R-squared	0.077	0.126	0.175

Regression results of Equation (2'), (3') and (4'). For all Equations the ICAS PD in the dependent variable is replaced by an average IRB PD, using at least three other IRB PDs for each firm (PD_{IRB}^{agv}). Equation (2') and (3') use "Panel D", and Equation (4') excludes 895 observations without information on the CET1 ratio from "Panel D", equivalently to the difference between "Panel B" and "Panel C". The dummy "Source = IRB" is equal to 1 if a bank uses its IRB PD for a firm for the mobilisation of its loan to that firm, and equals 0 when an ICAS is instead used for the mobilisation of a loan to the same firm. Log CVAH denotes the logarithm of the collateral value after haircut of loans to a firm that are mobilised as collateral by each bank. “Liquidity utilisation” denotes the ratio of central bank liquidity provided to a bank relative to the total collateral after haircut mobilised by the same bank. CET1 ratio is the Tier 1 capital ratio of each bank. All results are estimated using firm-year fixed effects. Robust standard errors adjusted for clustering at the firm level are reported in parentheses. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

As mentioned earlier, the introduction of the SSM may have implied a regime shift, with potential implications for the stability of our results over time. Therefore, as a robustness check, we estimate equations (2) to (4) separately for the years 2014-2016 and 2017-2018. The results show that the coefficients tend to be estimated less precisely for the latter sample (Annex 3, Table A8). For example, the estimate of δ (the negative gap between IRB PDs and ICAS PDs) in equation (2) and (3) is no longer significant for the 2017-2018 sample. By contrast, the estimate of the interaction between the dummy and the collateral size when the IRB rating is used to mobilise the loan as collateral (capturing the loan size effect) in (3) and (4) is robust across samples. The results of a formal test of joint equality of the coefficients across the two samples are mixed, with clear evidence of parameter stability at the conventional confidence levels for equation (3) and, to lesser extent, for equation (2), but not for equation (4). These results could be interpreted as providing early evidence that the introduction of the SSM with a close and harmonised supervision of IRB models may have started to mitigate any risks of underestimation by IRBs (relative to ICASs). At the same time, since the results are rather mixed, more evidence over a longer sample would be needed before drawing firmer conclusions.

Finally, as outlined in Section 4, we check whether results in equation (3) and (4) are affected by the endogeneity of the collateral value after haircut (CVAH), stemming from the fact that the contemporary PD has implications for the eligibility of the bank loan as collateral and for the determination of the relevant valuation haircut. In order to investigate this hypothesis, we re-estimate the equations with two-stage least squares using the CVAH lagged by one year as an instrumental variable. Notwithstanding the loss of observations, which contributes to somewhat greater standard errors, the estimates of the loan size effect are confirmed: the estimated coefficient on the interaction of the source dummy D_{ijt} with the collateral value after haircuts is statistically significant and close to the value of -0.2 reported in our benchmark estimates of equations (3) and (4) (Annex 3, Table A9).[30]

6. Conclusion

Using data on credit ratings of bank loans to euro area firms from two different categories of credit assessment systems (commercial banks' IRBs and central banks' ICASs), we find evidence that the internal ratings from banks tend to underestimate credit risk compared to the ratings from central banks when the underlying corporate loans are used as collateral to borrow liquidity from the Eurosystem. In particular, we find that while IRB ratings appear to be on average more conservative than ICAS ratings for the entire population of corporate loans rated by both IRBs and ICASs, this relationship does no longer hold when we focus on the narrower set of corporate loans that are actually used as Eurosystem collateral. In fact, by exploiting the heterogeneity across banks in the use of different types of ratings for the assessment of the eligibility of the corporate loans as Eurosystem collateral, we show that the IRB ratings actually used by banks in monetary policy operations tend to be less conservative than the corresponding ICAS ratings, particularly for larger bank loans. These results are confirmed when we use the average IRB PD assigned to the same debtor by different IRB banks instead of the corresponding ICAS ratings as benchmark. Overall, our findings suggest that the internal measurement of credit risk by banks may to some extent incorporate considerations about collateral optimisation when the related corporate loans are used to borrow liquidity at the Eurosystem's collateralised operations. Our approach helps to overcome well-known challenges to validate models for low-default portfolios, which are predominant in our sample given the relatively high credit quality threshold for Eurosystem collateral eligibility.

Our paper relates to the emerging literature on how the use of IRB models for regulatory purposes may influence their credit risk estimates. This literature has so far focused on the use of IRBs for regulatory capital purposes and the possible incentives for banks to underreport credit risk in order to economise on regulatory capital (see, for instance, Behn et al., 2021, Berg and Koziol, 2017, Plosser and Santos, 2014). Our results suggest a separate collateral-related channel through which the acceptance of ratings from IRBs for public policy

[30] In addition, the negative impact of CVAH is relevant for all mobilised loans according to the IV regressions for equation (4), instead of only sufficiently large loans according to our results for equation (4) in Table 3, as the estimated coefficient on the source dummy D_{ijt} is slightly negative for the IV regression, whereas it is positive in Table 3.

purposes may give rise to incentives to underestimate credit risk. More precisely, thanks to the availability of a neutral benchmark provided by the central banks' ratings, we find evidence that the use of IRB ratings to assess the eligibility of corporate loans as collateral in the central bank liquidity operations (and also to determine the relevant valuation haircuts) may lead to banks underestimating the credit risk of their corporate loan portfolios for collateral optimisation purposes.

These results may provide useful information when thinking about how to improve the credit assessment framework of the Eurosystem's monetary policy operations, even if they are mainly based on corporate loan data from three euro area countries only (France, Italy and Austria). The current obligation for a Eurosystem counterparty to indicate *ex ante* whether it intends to use the central bank's ICAS or its own IRB as a primary source, which excludes the possibility of "rating hopping" if a debtor has ratings from multiple sources, helps to some extent to avoid a systematic bias in the use of ratings across different sources. However, it might be more effective to redefine the criteria for establishing the primary source when an ICAS is available. For instance, ICAS ratings could be automatically prioritised whenever they are available, thus contributing to reducing the reliance on external ratings (in line with FSB 2010, 2012). More generally, it may be beneficial to consider a cost-efficient expansion of ICASs within the Eurosystem. This objective could be achieved by widening the rating coverage of the existing ICASs and/or investing in the development of new ICASs with a view to assigning ratings to a broader range of asset classes.

Finally, our findings may also be of interest for banking supervisors and commercial banks when thinking about how to improve existing statistical tests for the validation of credit assessment systems. Standard statistical tools for model validation (see, e.g., Basel, 2005), such as back-testing predicted vs realised default rates, are conducted at debtor-level, without taking into account the size of the banks' exposures. Our empirical finding that the likelihood of credit risk underestimation by IRBs relative to ICASs is higher for larger corporate loans suggests that the development of validation tests that weigh rated entities by the respective bank's exposure, or directly validate expected losses, could provide an interesting avenue for further research.

There are two caveats to the analysis that deserve some attention: first, most of our observations refer to corporate loans in three euro area countries only (France, Italy and Austria); second, the introduction of the SSM and various regulatory and supervisory initiatives to improve IRB models may have already started to mitigate the underestimation of credit risk for mobilised collateral, with positive spill-over effects on the risk management of monetary policy operations. Future research should aim to extend the analysis to a broader sample in terms of geographical coverage and to assess the effect of the shift in supervisory regime using a longer sample including the more recent data.

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Annex 1: Dataset and descriptive statistics

Table A1: Description of variables

Variable	*Description*	*Unit*
Firm information		
Country	Country of the firm, e.g. AT for Austria, BE for Belgium etc.	-
ICAS PD	Probability of default (PD) (in basis points from 3 to 10,000) over a 1-year horizon, which is provided by the ICAS of an NCB and associated with an individual firm.	Basis points
Average alternative IRB PDs	Average PD of a firm is based on at least three IRB PDs from different banks for the same firm.	Basis points
Bank information		
NCB	Home country of the bank, which corresponds to the relevant national central bank (NCB).	-
Tier 1 capital ratio (CET1)	Measure according to Basel framework.	Percent
Liquidity utilisation rate	Ratio between central bank credit provided to the bank and collateral mobilised by the bank, measured from 0% to 100%.	Percent
Firm-bank information		
IRB PD	PD (in basis points from 3 to 10,000)[1] over a 1-year horizon, which is provided by the IRB bank and associated with an individual firm.	Basis points
Collateral value after haircuts	Nominal outstanding amount of the bank loan to a firm, which is mobilised as collateral, minus maturity, coupon, and credit quality dependent haircuts.	EUR million
Primary source	The credit assessment source dummy for mobilised collateral is equal to one if the firm's credit quality was assessed with an IRB PD and zero if the firm was assessed with an ICAS PD.	Dummy

Notes: 1) As some banks report PDs using the 0.03% regulatory floor used for the calculation of capital requirements, we floor all PDs to this level.

Table A2: Summary statistics for firm, firm-bank, and bank characteristics, Panel A-D

Dataset	*Unit*	*N*	*Mean*	*Std. Dev.*
Panel A				
PD ICAS	Basis points	182,937	43.64	125.22
PD IRB	Basis points	226,493	73.02	155.23
Panel B				
PD ICAS	Basis points	13,128	44.30	139.20
PD IRB	Basis points	16,896	43.53	76.08
Loan value after haircuts	EUR million	16,896	4.66	14.63
Primary source	Dummy	135	0.53	-
Panel C				
PD ICAS	Basis points	12,317	45.21	143.42
PD IRB	Basis points	15,763	43.94	74.63
Loan value after haircuts	EUR million	15,763	4.65	14.36
Primary source	Dummy	114	0.54	-
Tier 1 capital ratio	Percent	114	14.40	4.29
Utilisation rate	Percent	114	54.94	24.93
Panel D				
PD IRB	Basis points	30,906	38.13	47.83
Average alternative IRB PDs	Basis points	30,906	72.80	90.56
Loan value after haircuts	EUR million	30,906	2.81	16.60
Primary source1)	Dummy	110	0.52	-
Tier 1 capital ratio2)	Percent	87	14.70	4.66
Utilisation rate2)	Percent	87	56.68	24.12

Notes: 1) In Panel D, we do not restrict to firms that have both an IRB and ICAS PD. In consequence, Panel D includes banks that mobilise collateral with ICAS PDs as well as their own IRB PDs, due to insufficient coverage of the ICAS system. 2) Equivalently to the difference between Panel B and Panel C, the lack of information on the Tier 1 capital ratio for a few banks means that these statistics refer to the 30,011 firm-year observations used for equation (4’).

Annex 2: Cross-comparison of IRB and ICAS ratings

A2.1 Discriminatory and calibration power

Following the results in section 5 where we found evidence of underestimation of IRB PDs relative to ICAS PDs for larger corporate loans, the present subsection aims to answer the question if conventional statistical tests are able to detect such underestimation pattern. Therefore, we provide an analysis of the calibration and discriminatory power of IRB and ICAS models in our data set. Table A3 compares the yearly average PDs at the beginning of the year with the average realised default rates over the respective year for the full sample of IRB and ICAS ratings between 2014 and 2018.[31]

We observe a relatively close match between actual default rates and model-based PDs for ICASs, with ICAS somewhat overestimating default rates for each year. On the contrary, IRB models underestimate default rates for the first three years and overestimate default rates for 2017 and 2018 to a significant extent. This sign inversion could be explained by the through-the-cycle (or hybrid) nature of IRB PDs and, in part, indicate a stronger supervisory oversight after the setup of the SSM (see, for example, the SSM’s targeted review of internal models initiated at the beginning of 2016 and described in ECB, 2021).

Table A3: Comparison of ex ante PDs (beginning of the year) and ex post realised default rates (over the calendar year) for ICAS and IRB ratings

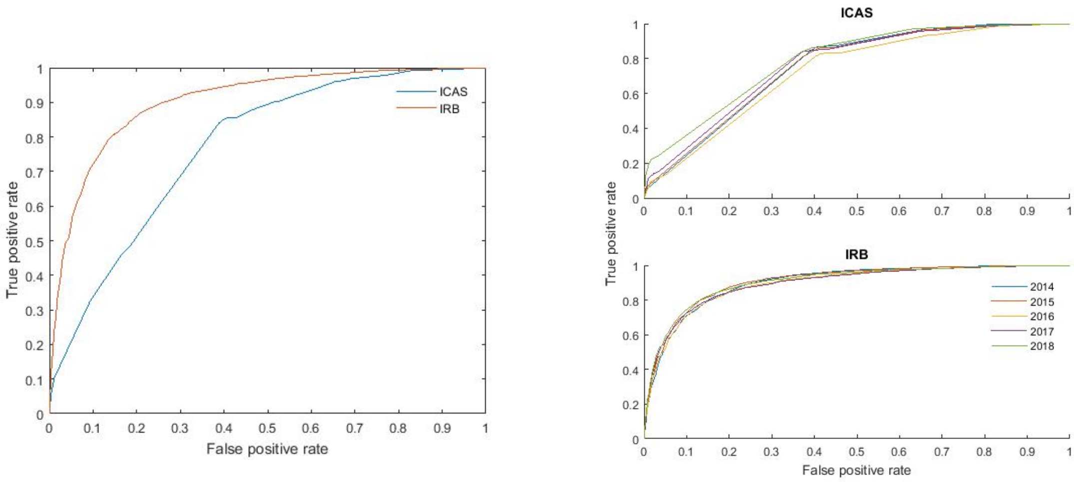
Dataset	*N*	*PD* (in bps)	*Actual Default Rates* (in bps)
IRBs			
2014	1,304,862	306.51	445.47
2015	1,581,385	256.45	324.37
2016	1,306,407	274.82	280.65
2017	1,275,873	283.19	244.40
2018	1,498,372	252.30	194.46
ICAS			
2014	180,901	66.56	48.42
2015	167,531	57.41	34.20
2016	173,074	48.87	34.26
2017	173,608	43.64	31.28
2018	177,364	39.13	36.20

[31] Panel A-D are based on information at end-of-year while excluding defaults in the respective year from the analysis.

As regards the discriminatory power, we analyse in Figure A1 below the Receiver Operating Characteristic (ROC) for the IRB and ICAS data underlying Table A3.[32] For the plot on the left-hand-side, the ROC curve for IRBs (orange line) is significantly steeper at the left end compared to the ROC curve for ICAS models (blue line). Furthermore, the two plots on the right-hand-side (rhs) confirm that this effect is persistent over time (see Figure A1 upper rhs for ICAS models and lower rhs for IRB models). Even though the ROC curves cannot be directly compared because they are based on different portfolios and rating grades/PDs of different granularity, their striking difference suggests a higher discriminatory power for IRB models.

Overall, we conclude that by looking at the full portfolio of IRB loans, conventional statistical tests do not raise any concerns with respect to underestimation of actual credit risks for our dataset, in particular for more recent years.

Figure A1: Receiver Operating Characteristic (ROC) curve for IRBs and ICASs



[32] The ROC curve is plotting the true positive rate (TPR) against the false positive rate (FPR) at different discrimination thresholds, e.g. if the discrimination threshold is set at 0.1%, then all PDs below will be classified as non-defaults (negative) while all PDs above will be classified as defaults (positive). The steeper the ROC curve is at the left end, the better is the discriminatory power of a model. For a more detailed review, see Basel Committee on Banking Supervision (2005).

A2.2 Introduction of Fixed Effects and Dummy Variables

Below, we motivate the introduction of country and time fixed effects in our empirical setting. By restricting our data set to firms whose loans have been mobilised as collateral (Panel B), IRB PDs appear less conservative compared to ICAS PDs between 2016 and 2018 (see Table A4). This is a striking result given our previous findings for the performance of IRB and ICAS models, in particular that IRBs on average overestimated default rates for 2017 and 2018 more than ICASs. It further supports our argument that banks tend to underestimate PDs for only some firms, which is not picked up by conventional statistical methods.

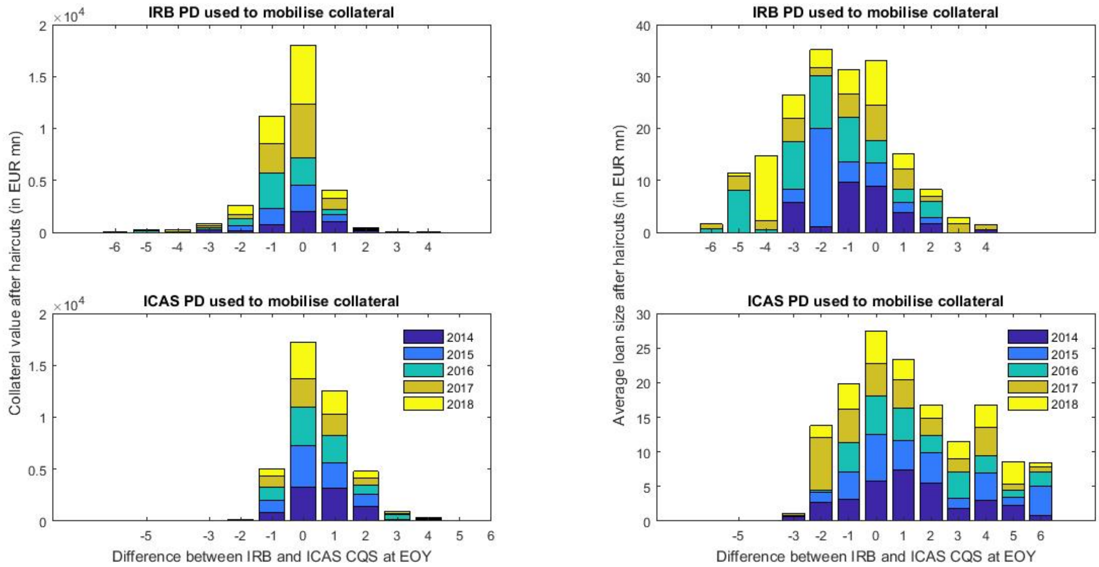
Table A4: IRB PDs and ICAS PDs at end-of-year (Panel B), by year

Year	*N*	*IRB*		*ICAS*	
		PD (in bps)	*Std. DV*	*PD* (in bps)	*Std. Dev*
2014	2,487	44.75	89.85	30.00	35.65
2015	3,206	43.46	63.92	32.80	31.07
2016	3,434	51.53	95.86	59.05	241.60
2017	3,729	40.75	68.31	49.27	130.10
2018	4,040	38.59	61.62	41.52	100.30
Total	**16,896**	**43.53**	**76.08**	**43.44**	**135.93**

Figure A2 below is essentially an illustration of the estimates related to Equation (3) of Table A6 Column (1). We stratify Panel B by the selected primary source of a bank, i.e. by banks that used their own IRB PD or the corresponding ICAS PD to mobilise collateral. Importantly, Figure A2 confirms our finding that, for firms whose loans are mobilised as collateral with an IRB PD, these PDs tend to be less conservative than ICAS PDs. Moreover, the opposite is true for collateral, which was mobilised with an ICAS PD. The upper chart left-hand side (lhs) shows that the distribution of the total collateral value is left-skewed, hence IRB PDs, and consequently the corresponding depicted Credit Quality Step (CQS) level, are on average lower compared to ICAS PDs if collateral is mobilised with an IRB PD. On the other hand, the lower chart (lhs) shows a distribution that is right-skewed for collateral mobilised with an ICAS PD. Both patterns seem to be persistent over time.

The described pattern is also evident if we look at the distribution of the average loan size mobilised as collateral (see charts right-hand side). For example, the upper chart (rhs) suggests that underreporting exists for IRB PDs, in particular for large collateral exposures, which is usually hard to determine. Overall, these results could provide some tentative evidence (more formally assessed through econometric tools in the empirical analysis) that banks ‘choose’ the less conservative credit assessment system as primary source for mobilising collateral.

Figure A2: Total mobilised collateral value (lhs) and average mobilised loan exposure (rhs) separated by primary source, across years (Panel B), by difference between IRB and ICAS PD buckets

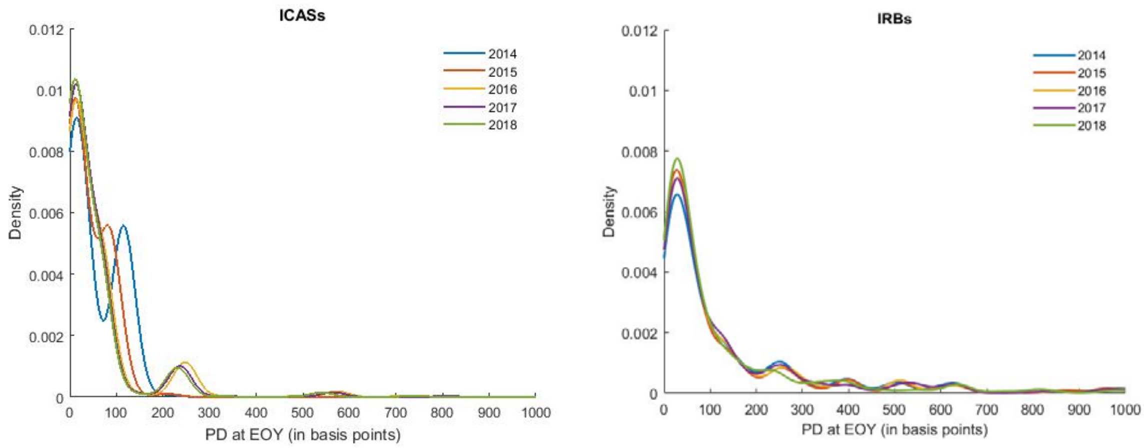


The IRB and ICAS PDs are mapped into buckets, so-called credit quality steps (CQS). Such CQS are used to determine valuation haircuts and eligibility of collateral for monetary policy operations and (with different PD-CQS mappings) to determine risk weights based on the standardised approach in the Capital Requirements Regulation.

A2.3 Loan Portfolio Distribution

We look at the average quality of IRB and ICAS portfolios at the *end of the year* in our data set. Figure A3 compares the kernel density of the IRB and ICAS PDs across the sample period. We find that the quality of the portfolios seems to have been lower in 2014, particularly for ICAS portfolios. In subsequent years, densities indicate portfolios of higher quality, probably reflecting the cyclical upturn, with the years 2015 to 2017 being quite similar in shape for IRBs. Given the shape of the densities for IRBs and ICASs it becomes evident that the focus of the empirical analysis is on high-quality credit portfolios.

Figure A3: Kernel density of IRB PDs and ICAS PDs on 31 December of each year



Annex 3: Full empirical results

Table A5: Estimation of Equation (2)

	(1)	(2)	(3)	(4)	(5)
	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$
Source = IRB	-0.306***	-0.422***	-0.427***	-0.374***	-0.407***
	(0.016)	(0.048)	(0.048)	(0.048)	(0.054)
Firm FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	No	No
Country x Year FE	No	No	No	Yes	No
Firm x Year FE	No	No	No	No	Yes
Observations	16896	16896	16896	16896	16896
Adj. R-squared	0.139	0.738	0.738	0.742	0.725

This table provides the regression results of Equation (2) estimated using “Panel B”. The dependent variable is the logarithm of the ratio between IRB PD and ICAS PD. The dummy “Source = IRB” is equal to 1 if a bank uses its IRB PD to assess the credit quality of the borrower for the mobilised corporate loan, and to 0 when an ICAS PD is instead used. Column (1) is estimated using “pooled” OLS (without fixed effects); column (2) includes firm fixed effects, column (3) firm and year fixed effects, column (4) includes firm and country-year fixed effects; column (5) includes firm-year fixed effects (corresponding to the first column in Table 3). Robust standard errors adjusted for clustering at the firm level are reported in parentheses. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

Table A6: Estimation of Equation (3)

	(1)	(2)	(3)	(4)	(5)
	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$
Source = IRB	-0.304***	-0.355***	-0.360***	-0.311***	-0.331***
	(0.016)	(0.049)	(0.049)	(0.049)	(0.055)
Source = ICAS × log CVAH	0.052***	-0.010	-0.010	-0.013	-0.044***
	(0.009)	(0.012)	(0.012)	(0.012)	(0.015)
Source = IRB × log CVAH	-0.017	-0.168***	-0.168***	-0.163***	-0.200***
	(0.011)	(0.017)	(0.017)	(0.017)	(0.020)
Firm FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	No	No
Country x Year FE	No	No	No	Yes	No
Firm x Year FE	No	No	No	No	Yes
Observations	16896	16896	16896	16896	16896
Adj. R-squared	0.141	0.742	0.743	0.746	0.737

This table provides the regression results of Equation (3) estimated using “Panel B”. The dependent variable is the logarithm of the ratio between IRB PD and ICAS PD. The dummy “Source = IRB” is equal to 1 if a bank uses its IRB PD to assess the credit quality of the borrower for the mobilised corporate loan, and to 0 when an ICAS PD is instead used. CVAH denotes the logarithm of the collateral value after haircut of loans to a firm that are mobilised as collateral by each bank. Column (1) is estimated using “pooled” OLS (without fixed effects); column (2) includes firm fixed effects, column (3) firm and year fixed effects, column (4) includes firm and country-year fixed effects; column (5) includes firm-year fixed effects (corresponding to the second column in Table 3). Robust standard errors adjusted for clustering at the firm level are reported in parentheses. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

Table A7: Estimation of Equation (4)

	(1)	(2)	(3)	(4)	(5)
	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$	$\log \frac{PD_{IRB}}{PD_{ICAS}}$
Source = IRB	0.263***	0.234**	0.239**	0.604***	0.646***
	(0.059)	(0.106)	(0.107)	(0.111)	(0.129)
Source = ICAS × log CVAH	0.061***	0.008	0.009	0.010	-0.010
	(0.009)	(0.012)	(0.012)	(0.012)	(0.016)
Source = IRB × log CVAH	0.011	-0.163***	-0.164***	-0.159***	-0.193***
	(0.011)	(0.017)	(0.017)	(0.017)	(0.020)
Source = ICAS × Liquidity utilization	1.346***	0.254***	0.295***	0.387***	0.392***
	(0.069)	(0.051)	(0.056)	(0.061)	(0.077)
Source = IRB × Liquidity utilization	-1.643***	-1.090***	-1.035***	-1.083***	-1.309***
	(0.073)	(0.096)	(0.098)	(0.100)	(0.118)
Source = ICAS × CET1 ratio	0.847***	2.397***	2.478***	3.963***	4.367***
	(0.216)	(0.481)	(0.512)	(0.512)	(0.571)
Source = IRB × CET1 ratio	3.214***	2.950***	2.974***	2.568***	3.545***
	(0.377)	(0.290)	(0.302)	(0.337)	(0.364)
Firm FE	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	No	No
Country x Year FE	No	No	No	Yes	No
Firm x Year FE	No	No	No	No	Yes
Observations	15763	15763	15763	15763	15763
Adj. R-squared	0.157	0.753	0.753	0.757	0.752

This table provides the regression results of Equation (4) estimated using "Panel C". The dependent variable is the logarithm of the ratio between IRB PD and ICAS PD. The dummy "Source = IRB" is equal to 1 if a bank uses its IRB PD to assess the credit quality of the borrower for the mobilised corporate loan, and to 0 when an ICAS PD is instead used. CVAH denotes the logarithm of the collateral value after haircut of loans to a firm that are mobilised as collateral by each bank. "Liquidity utilisation" denotes the ratio of central bank liquidity provided to a bank relative to the total CVAH mobilised by the same bank. "CET1 ratio" denotes the Common Equity Tier 1 (CET1) ratio of each bank. Column (1) is estimated using "pooled" OLS (without fixed effects); column (2) includes firm fixed effects, column (3) firm and year fixed effects, column (4) includes firm and country-year fixed effects; column (5) includes firm-year fixed effects (corresponding to the third column in Table 3). Robust standard errors adjusted for clustering at the firm level are reported in parentheses. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

Table A8: Robustness check splitting the sample into 2014-2016 and 2017-2018

	2014-2016			2017-2018		
	Equation (2) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (3) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (4) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (2) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (3) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (4) $\log \frac{PD_{IRB}}{PD_{ICAS}}$
Source = IRB	-0.440***	-0.348***	0.704***	-0.188	-0.194	1.980***
	(0.058)	(0.060)	(0.151)	(0.123)	(0.126)	(0.292)
Source = ICAS × log CVAH		-0.043***	-0.019		-0.048**	-0.034
		(0.017)	(0.018)		(0.024)	(0.023)
Source = IRB × log CVAH		-0.206***	-0.203***		-0.191***	-0.185***
		(0.024)	(0.023)		(0.031)	(0.031)
Source = ICAS × Liquidity utilization			0.167**			2.115***
			(0.074)			(0.299)
Source = IRB × Liquidity utilization			-0.897***			-2.358***
			(0.163)			(0.187)
Source = ICAS × CET1 ratio			5.703***			7.573***
			(0.741)			(1.259)
Source = IRB × CET1 ratio			2.021***			7.301***
			(0.456)			(0.615)
Firm x Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9127	9127	8429	7769	7769	7334
Adj. R-squared	0.793	0.804	0.816	0.644	0.655	0.703

Regression results of Equation (2), (3), and (4) splitting the sample into 2014-2016 and 2017-2018. For equations (2) to (4), the dependent variable is the logarithm of the ratio between IRB PD and ICAS PD. Equation (2) and (3) use “Panel B”, Equation (4) uses “Panel C”. The dummy “Source = IRB” is equal to 1 if a bank uses its IRB PD for a firm for the mobilisation of its loan to that firm, and equals 0 when an ICAS is instead used for the mobilisation of a loan to the same firm. Log CVAH denotes the logarithm of the collateral value after haircut of loans to a firm that are mobilised as collateral by each bank. “Liquidity utilisation” denotes the ratio of central bank liquidity provided to a bank relative to the total collateral after haircut mobilised by the same bank. CET1 ratio is the Tier 1 capital ratio of each bank. All results are estimated using firm-year fixed effects. Robust standard errors adjusted for clustering at the firm level are reported in parentheses. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

Table A9: Robustness check using the lagged collateral value after haircuts as instrumental variable

	Equation (3) $\log \frac{PD_{IRB}}{PD_{ICAS}}$	Equation (4) $\log \frac{PD_{IRB}}{PD_{ICAS}}$
Source = IRB	-0.144	-0.097
	(0.150)	(0.216)
Source = ICAS × $\widehat{\log CVAH_t}$	0.009	0.022
	(0.019)	(0.022)
Source = IRB × $\widehat{\log CVAH_t}$	-0.195***	-0.196***
	(0.046)	(0.045)
Source = ICAS × Liquidity utilization		0.055
		(0.099)
Source = IRB × Liquidity utilization		-1.053***
		(0.179)
Source = ICAS × CET1 ratio		2.283***
		(0.651)
Source = IRB × CET1 ratio		3.169***
		(0.561)
Firm x Year FE	Yes	Yes
Observations	7864	7501
Adj. R-squared	0.739	0.747

This table provides the regression results of Equation (3) and (4) using a two-stage least-squares (2SLS) regression, whereby the logarithm of the collateral value after haircut (CVAH) at time *t*-1 is used as an instrument for the logarithm of the CVAH at time *t*. All the other variables are unchanged. All results are estimated using firm-year fixed effects. Robust standard errors adjusted for clustering at the firm level are reported in parentheses. Note: * indicates statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

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Alessandro Calza
European Central Bank, Frankfurt am Main, Germany; email: alessandro.calza@ecb.europa.eu

Julius-Benjamin Hey
Independent; email: julius.hey@gmx.de

Alessandro Parrini
European Central Bank, Frankfurt am Main, Germany; email: alessandro.parrini@ecb.europa.eu

Stephan Sauer
European Central Bank, Frankfurt am Main, Germany; email: stephan.sauer@ecb.europa.eu

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

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