# The Limits of Model-Based Regulation

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**ABSTRACT**

We investigate how the introduction of model-based capital regulation affected the performance of loans and overall credit risk of financial institutions. Model-based capital charges have been introduced to enhance the stability of the financial sector by making capital charges more sensitive to risk. Exploiting the staggered introduction of the model-based approach in Germany and the richness of our loan-level data set, we show that (1) internal risk estimates employed for regulatory purposes systematically underpredict actual default rates by about 0.5 to 1 percentage points; and (2) both actual defaults and losses given defaults are higher for loans that were originated under the new model-based approach. Furthermore, we document that large banks benefited from the reform as they experienced a reduction in capital charges and consequently expanded their lending at the expense of smaller banks that did not introduce the model-based approach. Our findings suggest that, counter to the stated objectives, model-based capital regulation adversely affected financial stability. They are consistent with the public choice or 'capture' theory of regulation, where complexity in regulation is created by incumbents (large banks) to increase barriers to entry, but at odds with public interest theories of regulation.

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# 1. Introduction

Following the financial crisis of 2008, policy makers around the world have concentrated their efforts on designing a regulatory framework that increases the safety of individual institutions as well as the stability of the financial system as a whole. While there is relatively wide agreement on the necessity of such measures, a deeper debate has evolved on the optimal level and structure of financial regulation, with the design of banks' capital charges at its core. In this context, the most important innovation in recent years has been the introduction of complex model-based capital regulation that was meant to promote the adoption of stronger risk management practices by financial intermediaries, and—ultimately—to strengthen the stability of the banking system (Basel Committee on Banking Supervision 2006). While proponents of such regulation argue that a complex financial system requires complex regulation to ensure an efficient allocation of resources, critics point out that complicated and often intransparent rules create high compliance costs and barriers to entry, while providing endless latitude for regulatory arbitrage. In this paper, we examine how the introduction of model-based capital regulation affected banks' credit risk and the overall stability of the financial system.

Prior to the introduction of model-based regulation, the regulatory environment was considered to be too simplistic and coarse. Bank assets were bucketed into broad risk categories and each category was subject to a flat capital charge (a flat tax). In contrast, regulation under Basel II relies on a complex array of risk models, designed and calibrated by banks themselves and subsequently approved by the supervisor.[1] As a consequence, many banks have more than 100 different risk models with several million parameters in place, all of which require constant validation and re-calibration by the bank's risk management and surveillance by the supervisor. The underlying economic principle behind this regulation can be termed as "He who pollutes should be taxed": The higher the risk on a specific position, the higher the capital charge. In a world with no informational and enforcement

[1] The latest revision of the regulatory framework, Basel III, retains the most important features of Basel II—most prominently the feature of model-based capital regulation—but introduces some corrective measures that are meant to address the most obvious problems with the previous framework.

problems, such a sophisticated regulation should unambiguously improve welfare.[2] The conclusion, however, becomes murkier in a world with informational and incentive constraints, where the theory of second best (Lipsey and Lancaster 1956) cautions us against making strong statements on welfare implications.

Model-based regulation is inherently complex and thus difficult to enforce.[3] The enforcement problem arises from the sheer amount of parameters that have to be estimated, and from the fact that banks have incentives to keep capital charges rather low. In the context of lending, it is now well understood that the quality of a the loan is not only a function of 'hard' and verifiable information, but also a function of 'subjective' and non-verifiable information. Model-based regulation induces a high weight on 'hard' information and thus provides perverse incentives to manipulate information on dimensions that reduce capital charges (Holmström and Milgrom 1991, Rajan et al. 2012). The inherent complexity of the model-based approach makes it very difficult—if not impossible—for the regulator to detect such behavior. As argued by Glaeser and Shleifer (2001), coarser regulation can be the optimal regulatory choice and may actually dominate more sophisticated forms of regulation in the presence of enforcement constraints.[4] Given the wide prevalence of informational and enforcement constraints, the effect of sophisticated model-based regulation on banks' credit risk remains an open question that we investigate in this paper.

To study this question, we exploit the institutional details of the German Basel II introduction in 2007 as well as the great granularity of our loan-level data set obtained from Deutsche Bundesbank. Following the reform, banks were allowed to choose between the

[2] By tying capital charges to actual asset risk, banks would no longer be penalized for holding very safe assets on their balance sheets, thus eliminating the distortion in the allocation of credit that accompanied the simple flat tax feature of Basel I. In line with the 'public interest' view, championed by Pigou (1932), complex regulation might be needed to achieve an efficient allocation of resources.

[3] As pointed out by Haldane (2013), already the number of pages in regulatory documents reveals ever-increasing complexity: Basel I in 1988 consisted of only 30 pages, while Basel II in 2007 had 347 pages, and Basel III doubled to 616 pages. A recent study by McKinsey estimates that a large bank needs to create 200 new full-time jobs to ensure compliance with regulatory rules (Härle et al. 2010).

[4] According to the 'public choice' theory (see, e.g., Stigler 1971, Posner 1974, Peltzman 1976, Becker 1983, Laffont and Tirole 1991), the regulatory process may be captured by small interest groups with high stakes in its outcome. In the context of financial regulation, this would mean that the financial industry created complex regulatory rules mainly for its own benefit. See also the 'grabbing hand' view of regulation articulated in Shleifer and Vishny (2002).

model-based approach (referred to as the internal ratings-based approach, short IRB) in which capital charges depend on estimated probabilities of default (PDs), and a more traditional approach that did not rely on internal risk parameters (referred to as the standard approach, short SA). The introduction of IRB required an extensive risk management system that had to be certified by the regulator, which imposed a significant compliance cost on the bank. Consequently, only very large banks found it worthwhile to introduce the new regulatory approach, while smaller regional banks opted for the standard approach to determine capital charges.

Clearly, banks that introduced the new approach were different from banks that remained under the traditional approach. Hence, a cross-sectional comparison between these two groups is likely to suffer from endogeneity bias. To circumvent this issue, we exploit variation in the regulatory approach within the group of banks that actually introduced model-based regulation. Importantly for the identification strategy, the introduction of the model-based approach within German banks was staggered over time. Risk models needed to be certified by the regulator on a portfolio basis, and regulators delayed the approval of each model until they felt comfortable about the reliability of the model.[5] In many cases, this meant waiting for more data on a specific portfolio of loans. We exploit this feature for identification, as illustrated in the following example: Consider a firm that has two loans, both from banks that opted to introduce the model-based approach. For one bank, the loan is in a portfolio that has already been shifted to the new approach, i.e., capital charges for this loan depend on the estimated PD. For the other bank the loan is in a portfolio that is still waiting for approval from the regulator. Although the bank estimates and reports a PD for this loan, the risk estimate does not have an influence on capital charges. Comparing PDs and actual default rates for loans to the *same* firm, but under different regulatory approaches, allows us to identify the effects of model-based capital regulation on these parameters.

We find that average PDs are always significantly lower for portfolios that have already been shifted to the new approach as compared with portfolios that are still waiting for ap-

[5] See Section 2 for details. Banks made an implementation plan that specified the order of implementation several years in advance. They were not allowed to pick individual loans for IRB, but had to shift whole portfolios at the same time. Furthermore, they were not allowed to move IRB portfolios back to SA.

proval. In stark contrast, there is no difference in actual default rates between the two types of portfolios in 2008 and 2009, and, what is more, the actual default rate in 2010 and 2011 is higher for portfolios under IRB as compared with portfolios under SA. Risk estimates for IRB loans systematically underpredict actual default rates by 0.5 to 1 percent, while there is no such effect in PDs for SA loans. Even for the same firm, if it has several loans from IRB banks, we find that the prediction error (i.e., the difference between a dummy for actual default and the PD of the loan) is significantly larger for loans that are subject to the IRB approach as compared with loans under SA. Finally, the result is also robust to the inclusion of bank fixed effects that control for bank heterogeneity. While the effect is particularly strong directly after the reform, it is also present in later periods and persistent until the end of the sample period in 2011. It should be noted that these estimates are likely to be biased downwards since one would expect that models that have not yet been certified by the regulator should perform worse. Our empirical strategy thus provides conservative estimates of the treatment effect.

To further sharpen our analysis, we focus on variation over time within the portfolio of loans that has already been transferred to the new approach. For loans originated in 2005 or 2006, the average PD is close to the actual default rate. In contrast, for loans originated after the Basel II reform, in 2007 or 2008, the actual default rate is much higher than the average PD, indicating a significant underestimation of credit risk for this set of loans. The fact that the underestimation effect is much stronger for IRB loans that were originated after the reform as compared with IRB loans originated before the reform indicates that our findings are not driven by the selection of IRB loan portfolios. While these loans differ in the time of origination, they find themselves within the same portfolios within IRB banks, i.e., within those portfolios for which the new approach has already been implemented.

The fact that PDs for IRB loans underpredict actual default rates does not necessarily mean that aggregate credit risk has increased. As risk-weights depend on loan-specific factors such as the loss given default or the exposure at default, the IRB approach provides additional incentives to improve loan quality, for example by increasing the level of collateralization. It could be that improvements in average loan quality outweigh the under-

prediction of actual default rates. To assess this, we compare banks' actual losses on IRB portfolios to those on SA portfolios. Although risk-weighted assets were considerably lower for loans under IRB at the time of loan origination, we find that banks actually lose more money on these loans as compared with loans under SA. This suggests that model-based regulation has failed to meet its objective of tying a bank's lending decisions to its risk-taking. Counter to the stated purpose of the reform, aggregate credit risk has increased, and complex model-based regulation has compromised financial stability. Interestingly, IRB banks did charge on average higher interest for IRB loan as compared to SA laons. Thus, even regualtory capital charges of IRB loan portfolios were reduced, banks were aware of the actual higher credit risk of these loans (i..e as reflected in the higher spreads). In line with the enforcement theory of regulation formulated by Glaeser and Shleifer (2001), society could benefit from simpler and more transparent rules.

Our results show that counter to the stated objectives, the regulation may have adversely affected bank stability. Thus, our findings provide some support for the 'public choice' theory, where incumbents lobby for sophisticated regulation as it helps them in extracting rents (Buchanan and Tullock 1975, Stigler 1971). The high compliance costs associated with the model-based approach meant that only the larger banks adopted this new approach. These large banks benefited from the new regulation and expanded their lending. Specifically, we find that banks that opted for the introduction of the model-based approach experienced a reduction in capital charges and consequently increased their lending by about 9 percent relative to banks that remained under the traditional approach.[6] Furthermore, these banks took greater risks and consequently generated higher returns on these loans. Consistent with the view espoused in Hellwig (2010), large banks exploited the model-based approach to 'economize on equity', reducing regulatory capital to a bare minimum and capturing the excess returns on equity associated with a high leverage ratio. While this behavior might have been privately optimal, it came at the expense of smaller banks that did not introduce the model-based approach, and ultimately at the expense of society, which had to bear

[6]We find that IRB banks increased their lending to the same firm significantly more than SA banks when the firm's PD (and hence the capital charge) was relatively low, but not when the firm's PD was relatively high. Thus, the reform achieved a tighter link between estimated PDs and a bank's lending decision, but the crucial link between PDs and actual default rates was lost in the process.

the costs of financial instability in the form of bank bailouts. Regulators—impressed by sophisticated new risk modeling techniques—failed to observe that the preferential treatment of large institutions under the model-based approach actually increased systemic risk. Besides, they also benefited from the introduction of complex regulation, as it facilitates what can be termed as regulatory 'empire building' à la Jensen and Meckling (1976). In recent years, the number of financial supervisors has dramatically increased across the world, at a much faster pace than the number of people working in the financial industry (Haldane 2013).[7]

Our paper connects several strands of the literature. A small but growing number of papers analyzes how ratings used for regulatory purposes affect financial stability. Most recently, the Basel Committee on Banking Supervision (2013) published an extensive study that showed a considerable impact of banks' modeling choices on risk-weights, documenting that estimated risk parameters vary widely across banks, even for the same exposures.[8] This generates a lot of uncertainty about risk-based capital ratios, and increasingly market participants seem to lose faith in the meaning of these measures, as documented by Demirgüç-Kunt et al. (2013).[9] Apart from its credibility problem, Hellwig (2010) argues that model-based capital regulation suffers from the fact that many of the risks involved are not exogenously given, but endogenously determined. As they depend on the behavior of the parties involved, they may change over time, and tracking them for regulatory purposes may be close to impossible.[10] An example is given by Acharya (2011), who argues that low risk weights for residential mortgage-backed securities made investment in this asset class attractive and endogenously turned it into a systemically important asset class. Moreover, Acharya et al. (2013) question the predictive abilities of risk weights, as they are based on accounting data and can only be updated ex-post. According to their argumentation, banks game risk-weighted assets by shifting their portfolios towards assets with lower risk weights, and false and underestimated risk weights automatically lead to excessive leverage (see also

[7] The most recent step in this direction was the creation of about 1,000 new supervisory positions at the European Central Bank.

[8] See also Firestone and Rezende (2013) and Le Leslé and Avramova (2012).

[9] See also Hagendorff and Vallascas (2013), Das and Sy (2012), or Mariathasan and Merrouche (2012).

[10] Rajan et al. (2012) apply this reasoning in the context of securitization.

Hoenig 2013). We document a shift in lending towards firms with low model-based PDs, followed by a systematic failure of internal risk models, hence providing direct empirical evidence in support of this view. What is more, our identification strategy in connection with the richness of our data set allows us to causally identify the effect of the shift towards model-based regulation on financial stability.

Further, our paper adds to the public choice literature on regulatory capture. A recent theoretical paper by Hakenes and Schnabel (2013) illustrates how the use of sophisticated risk models can induce inefficiently low levels of regulation in the banking sector. Empirical evidence that regulatory reform in the financial sector is often driven by industry interests rather than public interest is offered by Becker and Opp (2013), who examine a change in capital charges on insurance holdings of mortgage-backed securities. We add to this literature by showing that the introduction of model-based capital regulation—arguably the most important innovation in bank regulation in recent decades—mainly served the interests of the industry itself and compromised financial stability.

Our findings have important policy implications. As a response to the financial crisis in 2007/2008, the Basel committee has drafted a third revision of the regulatory framework for banks (Basel III). This framework continues to rely on model-based regulation, but further increases complexity by introducing—among other measures—capital conservation and countercyclical capital buffers. These new tools have been designed to address substantial weaknesses of the old framework that were identified in the recent crisis. While the measures might make sense individually, our results suggest that further increases in complexity are unlikely to increase financial stability. Although regulators at the national and at the European level are increasing their staff as a response to the reform, keeping track with ever-increasing complexity might prove to be difficult. The evidence presented in this paper provides support for the view that simpler and more transparent rules would be more effective in achieving the ultimate goal of financial stability.[11]

[11] See, e.g., Admati and Hellwig (2013), Haldane (2013), Acharya et al. (2013), Hoenig (2013), Haldane (2012), Haldane (2011), Hellwig (2010), or Hoenig (2010).

# 2. The introduction of model-based regulation in Germany

One of the main objectives of bank regulation in recent decades has been to establish a closer link between capital charges and actual asset risk. Regulators around the world promoted the adoption of stronger risk management practices by the banking industry in order to achieve the ultimate goal of a sound and stable international banking system.[12] In 1988, the Basel I agreement introduced risk-based capital charges by assigning bank assets into different risk groups (or buckets) with pre-assigned risk-weights (Basel Committee on Banking Supervision 1988). Risk-weighted assets were calculated by multiplying these risk-weights (0, 20, 50, or 100 percent) with actual asset values, and capital requirements were defined in terms of risk-weighted assets.

The next revision of this regulatory framework, referred to as Basel II, tried to establish a more granular link between capital charges and individual asset risk. The new framework, introduced in Germany in 2007, allowed banks to use their own internal risk models to determine capital charges for credit risk (Basel Committee on Banking Supervision 2006). Under the internal ratings-based (IRB) approach, each exposure gets assigned an individual risk weight that crucially depends on the bank's estimated probability of default (PD) for a specific borrower.[13] Risk-weighted assets are calculated by multiplying the—loan-specific—risk-weights with actual assets values, and capital requirements are defined in terms of risk-weighted assets as under Basel I.

In Germany, Basel II was implemented by revision of the Solvabilitätsverordnung (2006), which provides the foundation for national bank regulation. This code allows banks to choose between two broad methodologies for calculating their capital charges: The internal ratings-based approach described above and the so-called standard approach, that is

[12] The introduction of risk-weighted capital charges and potential problems related to them have been discussed in several papers, e.g. Behn et al. (2013), Brun et al. (2013), Hellwig (2010), Kashyap and Stein (2004), Daníelsson et al. (2001), Jones (2000), Brinkmann and Horvitz (1995). For an assessment from the side of the regulator see Basel Committee on Banking Supervision (1999).

[13] In the foundation IRB approach the bank estimates only the PD, while standard values are assumed for loss given default (LGD), exposure at default (EAD), and maturity of the loan. In the advanced IRB approach, the bank has to estimate all four parameters. As risk weights depend on the PD—our parameter of interest—in both approaches, we do not distinguish between the two in the empirical analysis.

basically equivalent to the old Basel I framework with fixed risk weights for corporate loans (100 percent of the loan amount net of collateral).[14]

The Solvabilitätsverordnung (2006) provides a comprehensive set of rules and guidelines for banks that want to use internal risk models for calculating their capital charges: PD models used for regulatory purposes should estimate creditors' one-year probability of default.[15] As the bank could have incentives to report low PDs in order to economize on regulatory capital, internal risk models are subject to a strong supervisory review—including on-site audit (see also Bundesbank 2004). In particular, the regulator requires a precise and consistent estimation of credit risk, and proof that the model has been used for internal risk management and credit decisions for at least three years before it may be used for regulatory purposes. Furthermore, the bank has to constantly validate its models and adjust them if their estimates are inconsistent with realized default rates. The supervisor certifies rating systems, continuously monitors compliance with minimum standards, and assesses banks' internal validation procedures (see also Bundesbank 2003).

PD models are estimated on a portfolio basis. For corporate loans, their most important determinant is accounting information from firms' financial statements (see, e.g., Initiative für den Finanzstandort Deutschland 2006; Krahnen and Weber 2001). For loans to small and medium enterprises (SMEs), where there is often a significant publication lag for accounting information, also target financial ratios or industry characteristics may be used. Besides these quantitative factors, also qualitative information such as a firm's management quality or its competitive situation can be included in the models. However, since such information is by definition hard to quantify its impact on the rating is rather limited. A prominent PD model used for the estimation of corporate credit risk is Moody's RiskCalc$^{TM}$ model (Moody's Analytics 2013). To obtain predicted probabilities of default for a given portfolio, historical information on corporate defaults is regressed on accounting information such as

[14] Exceptions are cases where borrowers have external credit ratings, as the SA allows banks to use these ratings to determine capital requirements. However, the German market for corporate bonds is very small; hence, very few companies have an external rating.

[15] According to § 125 of the Solvabilitätsverordnung (2006), a creditor is in default if (a) the bank has valid indications that the creditor will not be able to fulfill his obligations, or (b) the creditor is more than 90 days past due on his obligations.

the equity ratio, capital structure, net debt ratio, sales growth, net profit ratio, personnel cost ratio, payables payment period, or cash flow per liabilities. In a second step, estimates from this model are used to attribute predicted PDs to current and new borrowers. In cases where loan officers consider model outputs to be unreasonable they have the option to overwrite the predicted PD. However, if such overwrites occur to frequently, the regulator may ask the bank to revise its model. Furthermore, a bank has to revise its model if the annual validation process reveals a considerable discrepancy between predicted PDs and actual default rates.

Besides loan-specific variables such as the loss given default, the exposure at default and the maturity of a loan, the firm-specific PD estimate is the key ingredient for the calculation of risk-weighted assets. Figure 1 shows the relationship between estimated PDs and corresponding risk-weights, assuming standard values for the remaining parameters. Risk-weight curves are relatively steep for the lowest PDs and become flatter for higher PDs. This is in line with the objectives of the new agreement: To provide banks with incentives to introduce IRB, risk-weight curves were calibrated in a way that ensured that capital requirements would be substantially lower under IRB than under SA (Basel Committee on Banking Supervision 2006, p. 12).

To be eligible for the model-based approach to capital regulation, banks need to fulfill certain conditions and minimum disclosure requirements. Since the organizational efforts as well as the administrative expenses for the introduction of the new approach are high, only large banks opted for its introduction (of our sample of 1,603 German banks, only 45 banks applied for an IRB license; nevertheless these banks account for about 50 percent of the loans in our sample). The introduction of new rating models is a complex process, so that banks did not apply the new approach to all loans at once; rather, they agreed on a gradual implementation plan with the regulator.[16] The plan specified an order according to which different business units (loan portfolios) had to be shifted to IRB. As the calibration of a meaningful PD model requires a sufficient amount of data on past loan performance, banks typically started with loan portfolios in business units where they were relatively active. The phased roll-out of IRB means that during the transition, which typically lasts for several

[16] See Solvabilitätsverordnung (2006), §§ 64-67 for details on the implementation plan.

years, banks have both IRB and SA loans in their portfolios. We exploit this feature of the implementation process in our empirical section, where we compare PD estimations with actual default rates for loans that are subject to different regulatory approaches.

# 3. Data

Our principal source of data is the German credit register compiled by Deutsche Bundesbank. As part of its supervisory role, the central bank collects data each quarter on all outstanding loans of at least € 1.5 million.[17] The data set starts in 1993 and includes information on the lender's and the borrower's identity, the amount of the loan outstanding and several other loan characteristics. As a response to the Basel II reform, reporting requirements for the credit register have been expanded considerably from 2008 onwards. In addition to the previous information, banks now also report exposure-level information on the regulatory approach (SA or IRB) and the estimated probability of default (PD). For loans under the IRB approach, the reported PD is the one that is used to determine regulatory capital charges. For loans under SA, banks also have to report PDs if they are estimated internally. As IRB banks aim to transfer all eligible loan portfolios to the new approach once the respective model is certified by the regulator, they report PDs for both IRB loans and SA loans. We use PDs for SA loans as a benchmark against which we evaluate the performance of PDs for IRB loans. Further, the database contains information on risk-weighted assets and loan loss provisions in case a loan defaults. The provisioning rules for loan losses are specified in the Solvabilitätsverordnung (2006). Banks have to make provisions that correspond to the expected loss as soon as there is information about repayment problems or default of a specific borrower (see § 125 of Solvabilitätsverordnung (2006)). We combine this exposure-level data with annual bank balance sheet information from Bundesbank's BAKIS database and annual firm balance sheet information from Bundesbank's USTAN database.

Our sample includes 1,603 German banks, 45 of which opted for IRB following the

[17] Since we focus on corporate lending, this cut-off does not constitute a big issue for our analysis. When matching firm balance sheet information from the Bundesbank USTAN database to the credit register, we find that—in the matched sample—lending recorded in the credit register makes up about 80-90 percent of firms' overall bank debt on average.

introduction of Basel II. Panel A of Table 1 shows that the average IRB bank is larger and less capitalized than the average SA bank, whereas average ROA is similar in the two groups of banks. Further, there are relatively more cooperative banks among the group of SA banks, whereas IRB banks are mostly large and internationally active commercial banks. Our empirical setup allows us to analyze the predictive abilities of PDs for loans subject to different regulatory approaches within the group of IRB banks only.

Descriptive statistics on the loan level are presented in Panel B of Table 1 and grouped by the regulatory approach used for the determination of capital charges. There are about twice as many SA loans (80,961) as compared with IRB loans (45,246) right after the introduction of the new regulatory approach. The first line of the table shows the average change in the amount of loans outstanding around the introduction of Basel II.[18] The average IRB loan in our sample was increased by about 6.5 percent over the Basel II introduction, while the average SA loan was increased by about 1.4 percent. Information on PDs becomes available in the credit register from 2008 onwards. The average PD in 2008Q1 is slightly higher for SA loans (2.6 percent) as compared with IRB loans (1.4 percent). While the PD estimates the firm-specific probability of default, the risk weight for a specific loan also incorporates loan specific information (e.g., the collateralization of the loan). For SA loans the corresponding risk weight does not depend on the PD and is equal to 100 percent of the unsecured fraction of the loan amount.[19] Overall, this translates into an average risk weight of 68.5 percent for SA loans, which is considerably higher than the average risk weight for IRB loans (47.8 percent). Furthermore, banks are required to report loan loss provisions for loans in default. Since certain loans are backed by collateral or guarantees, the consequences of a borrowers's default may vary. For both SA loans and IRB loans, loan loss provisions in case of a default are around 45 percent. Since the German credit register does

[18]The sample includes all loans in the credit register that have an observation both before and after the reform. We calculate the change in lending around the reform by collapsing all quarterly data for a given exposure into single pre-event and post-event periods by taking the average of the two years before and the two years after the Basel II introduction. The change in lending is defined as the difference in the logarithm of these averages, so that there is one observation per loan.

[19]The Basel regulations include a discount for loans to small and medium enterprises (SMEs) as the regulator wants to promote lending to these firms. Specifically, under Basel II, loans to firms with a turnover of € 50 million or less are subject to lower capital charges, as regular risk weights are multiplied with a correction factor depending on the exact amount of the turnover.

not contain information on interest rates, we follow a procedure developed by Haselmann et al. (2013) to back out interest rates from the data that is available in the credit register. Specifically, we infer the repayment structure of the loan contract (e.g., whether it is repaid at the end of the contract period, linearly, or de-/progressively) from the quarterly data on loan amounts. We match this contract-level information with firm-level data on aggregate interest payments obtained from Bundesbank's USTAN database. This procedure allows us to back out effective annual interest rates on the loan contract level.[20] As displayed in the last line of Panel B, interest rates for loans under the standard approach are on average slightly lower (6.8 percent) than interest rates for loans under IRB (7.5 percent).

Finally, Panel C of Table 1 contains descriptives for several firm-level variables. First, we calculate a PD variable on the firm level by taking the average of all PDs assigned to the firm (by different banks) in the first quarter of 2008. The average for this firm-level variable is 2.2 percent and lies between the average PD for SA loans and the average PD for IRB loans. Second, several accounting variables are obtained by a hand-match of the Bundesbank USTAN database with the credit register.[21] The match was conducted based on company name, location, and industry segment that are available in both data sources. The matched dataset contains detailed information on lending relationships and balance sheet items for 5,961 distinct firms. We report summary statistics on total assets, debt to assets and return on assets (ROA) for this sample. The average size of our sample firms is 154 million euros, the average debt to asset ratio is 34.3 percent, and the average return on assets is 7.9 percent.

# 4. Empirical strategy

In this section, we carefully explain the empirical strategy employed in order to validate the main argument of our paper: That the introduction of model-based capital regulation led to a systematic failure of banks' internal risk models. For each quarter, we estimate the

[20] See Haselmann et al. (2013) for further details.

[21] Even though the credit register and the accounting information all come from Deutsche Bundesbank, the two datasets have no unique identifier. For a detailed description of the USTAN database see Bachmann and Bayer (2013).

following equation in order to test whether PDs for IRB loans systematically underpredict actual default rates:

$$y_{ijk} = \alpha + \delta \cdot 1_{(k \in T)} + \varepsilon_{ijk}, \tag{1}$$

where $j$ denotes the individual bank, $i$ denotes the individual firm, and $k$ indicates whether the loan belongs to an SA or to an IRB portfolio within the bank. The dependent variable $y_{ijk}$ is defined as the difference between a dummy that indicates actual default and the PD that bank $j$ attributes to loans to firm $i$. As PDs for loans vary between 0 and 1, $y_{ijk}$ is positive for loans that actually default and negative for loans that do not default. The indicator variable $1_{(k \in T)}$ takes a value of 1 if loans to firm $i$ belong to the IRB portfolio of bank $j$, and 0 if they belong to the SA portfolio. Further, the equation includes a constant $\alpha$ and a random error term $\varepsilon_{ijk}$. In order to allow for potential correlation among default events for loans to the same firm, standard errors are clustered at the firm level in all regressions.

If we want to interpret the coefficient of interest, $\delta$, as the causal impact of the regulatory approach on the prediction error $y_{ijk}$ for a specific loan, the covariance between $1_{(k \in T)}$ and $\varepsilon_{ijk}$ should be equal to zero ($Cov(\varepsilon_{ijk}, 1_{(k \in T)}) = 0$). As banks that introduced the model-based approach tend to be larger, internationally more active and more sophisticated than banks that remained under the traditional approach, an estimation based on loans from both types of banks could have biased our coefficients. Fortunately, the institutional details of the German Basel II introduction described in Section 2 allow us to circumvent this concern by using within-bank variation in the regulatory approach. IRB institutions did not shift all their portfolios to the new approach at the same time, so that we can use variation between loans that have already been shifted to IRB and loans that are still under SA to identify $\delta$ in Equation (1).

Although the approach described above addresses many concerns, coefficients could be biased if there are omitted factors that determine whether firms are assigned to SA or IRB portfolios within IRB banks. To address this issue, we focus on firms that borrow from at least two banks, one bank where loans to the firm belong to a portfolio that has already been shifted to IRB and one bank where they are still under SA. Depending on the quarter, our sample contains up to 19,864 loans to 4,971 distinct firms that fulfill this criterion. For

each quarter, we estimate:

$$y_{ijk} = \alpha_i + \alpha_j + \delta \cdot 1_{(k \in T)} + \varepsilon_{ijk}, \tag{2}$$

where $\alpha_i$ and $\alpha_j$ denote firm and bank fixed effects, respectively, and the remaining variables are defined as in Equation (1). By adding $\alpha_i$ and $\alpha_j$ we are able to systematically control for heterogeneity across banks and across firms. That is, we can check whether the prediction error for loans to the same firm is greater when IRB instead of SA is used by the bank, and—similarly—whether the estimation error for loans from the same bank is greater when IRB instead of SA is used for loans to a specific firm.

The identification strategy described above provides an unbiased estimate of the impact of the regulatory approach on the prediction error as long as there is no systematic relationship between the point in time at which a specific portfolio is shifted to IRB and the bank's ability to estimate PDs for loans in that portfolio. As described in Section 2, banks typically shifted those portfolios first for which they had a sufficient amount of data to calibrate a meaningful PD model that could be certified by the regulator. Hence, any bias from selection of IRB portfolios should work against us: If anything, banks should be better able to predict actual default rates for those loan portfolios that have been certified by the regulator (i.e., those portfolios for which they have sufficient data and experience). Nevertheless, we further refine the identification strategy to remove any remaining doubts.

We argue that model-based regulation induced an overreliance on hard information, thus giving rise to a systematic failure of PD models. If this argumentation holds true, the effect should be particularly pronounced for loans that were originated after the introduction of model-based regulation. For those loans, capital charges depended on PD estimates at the time of loan origination, while they did not for loans that were originated before the reform and consequently shifted to IRB. We exploit this time series variation in the loan issuance date to circumvent the selection concern. Specifically, we restrict ourselves to loans that actually use the IRB approach and check whether the underestimation of actual default rates is greater for loans that were originated after the reform as compared with loans that were

originated before the reform. We estimate the following equation:

$$y_{ij} = \alpha_j + \delta \cdot 1_{(c \in B)} + \varepsilon_{ij}, \tag{3}$$

where $1_{(c \in B)}$ is an indicator variable that takes a value of 1 if the the IRB loan was issued after the implementation of Basel II (in the year 2007) and 0 otherwise. Note that this specification is not prone to selection concerns and therefore allows for an unbiased estimate of the effect of the regulatory approach on the functioning of PD models.[22]

# 5. Empirical results

## 5.1. Descriptive analysis

We start by assessing how PD estimates from banks' internal risk models compare with actual default rates for a respective set of loans. The information on PDs—and with it the information on actual defaults—becomes available in the credit register in 2008Q1. As described above, the analysis in this section focuses on IRB and SA loans from IRB banks only. Although the information is available on a quarterly basis, we evaluate loan portfolios once per year—at the end of each year—for reasons of presentability.[23] As stated in Section 2, PDs should estimate one-year default rates and a loan is considered to be in default if the borrower is 90 days past due on his obligations. Accordingly, the dummy variable *Actual Default* captures whether a loan is in default in at least one of the four quarters following the one in which the PD is evaluated. Importantly, all loans that are already in default in a respective quarter are excluded from the analysis.

Panel A of Table 2 shows descriptive statistics for lending relationships under IRB. There are 50,163 lending relationships in our sample that had already been shifted to IRB in 2008. During the sample period from 2008 to 2011, additional portfolios are shifted

[22] In contrast to previous estimations it is difficult to include also firm fixed effects in these regressions, as there are relatively few firms that obtained new loans both before and after the reform.

[23] Results for the remaining quarters are similar to the results we report, and available from the authors upon request. See also Figure A.1 in the appendix for an overview of average PDs and actual default rates for all quarters.

to IRB. Relationships that were under SA in 2008 but are moved to IRB before 2011 are constantly classified as SA loans, since this was the regulatory regime under which they were originated. New relationships are classified according to the regulatory approach under which they were issued. When comparing model based PDs with actual default rates, we observe that PDs for IRB loans significantly underestimated actual defaults in 2008, 2009, and 2011. Only in 2010, a year in which the actual default rate is considerably lower than in previous years, the estimated PDs and actual defaults of IRB loans match.

In Panel B of Table 2 we repeat the analysis presented in Panel A for those loans that were still subject to the standard approach in 2008. These portfolios will be transferred to IRB once the respective model is certified by the regulator. While the underlying PD models should hence be similar for IRB loans and SA loans, capital charges under IRB depend on the estimated PDs while capital charges under SA do not. Interestingly, while PDs for IRB loans underestimated actual defaults on average, we do not find a similar pattern for IRB banks' SA loans. In 2008, the actual default rate almost matches the average PD, and in the remaining years it is even lower than the average PD (especially in 2010, a year with a very low actual default rate).

Figure 2 plots average PDs and actual default rates for IRB loans and SA loans over time.[24] In line with our expectation, average PDs for IRB loans are always lower than average PDs for SA loans. As we will show in Section 7, IRB banks have shifted their lending more towards firms with low model-based PDs as capital charges under IRB are particularly low for loans to these firms. The differences between the two types of loans are both statistically (see Panel C of Table 2) and economically significant: Average PDs for IRB loans fluctuate between 0.0151 (in 2008) and 0.0201 (in 2010), while average PDs for SA loans are 25 to 80 percent larger and fluctuate between 0.0235 (in 2011) and 0.0284 (in 2009). Kernel density plots for PDs further illustrate this point (see Figure 3). Clearly, the distribution for IRB loans is to the left of the distribution for SA loans in all years. This is confirmed in a Kolmogorov-Smirnov test for equality of distributions: The hypothesis that the distributions for SA loans and IRB loans are equal can be rejected at the 1 percent level

[24] Again, for reasons of presentability, we evaluate loan portfolios only once a year. Results for the remaining quarters are very similar (see Figure A.1 in the Appendix).

in all cases.

Panel C of Table 2 and the lower part of Figure 2 further present corresponding actual default rates for the two sets of loans. In stark contrast to PDs, actual default rates are similar for both portfolios in 2008 and 2009, and, what is more surprising, significantly higher for IRB loans in 2010 and 2011 as compared with SA loans. This observation is in line with our prediction that loan quality is likely to deteriorate under IRB following the reform.

Finally, Panel C of Table 2 also reports differences in the difference between actual default rates and average PDs. In all years, this difference is significantly larger for IRB loans: Compared to PDs for SA loans, PDs for IRB loans significantly underestimate actual default. Albeit illustrative, the latter findings might be explained by borrower or bank specific factors. We therefore proceed by testing our assertions more formally in a regression framework.

## 5.2. Regression framework: IRB versus SA loans

Results for Equations (2) are presented in Table 3. We start with the specification without any fixed effects in the first four columns and estimate the equation separately for each quarter in order to ensure that each loan turns up only once in each regression.[25] In line with the findings in the previous section, the regressions show that the estimation error is significantly greater for IRB loans as compared with SA loans, i.e.—compared to PDs for SA loans—PDs for IRB loans significantly underpredict actual default rates.[26] Next, we add firm fixed effects in columns 5 to 8. In these tests, the sample is constrained to firms that have at least one IRB loan and at least one SA loan from an IRB bank. The coefficient for the IRB loan dummy remains significantly positive in all cases, which means that even within the same firm, PDs are more likely to underpredict actual default if IRB instead of SA is used for a specific loan.

[25] Again, we constrain ourselves to 2008Q4, 2009Q4, 2010Q4, and 2011Q4 for reasons of presentability. Results for the remaining quarters are very similar and available from the authors upon request.

[26] The coefficients for the IRB loan dummy in columns 1-4 correspond to the differences in differences in Panel C of Table 2.

As a final test, we complete the specification by adding bank fixed effects in columns 9 to 12 of Table 3. Except for 2010, the coefficient for the IRB loan dummy remains significantly positive, which means that—within the same bank—underprediction of actual default is more likely if IRB instead of SA is used for a particular loan. Overall, empirical results provide strong support for our assertion that the introduction of the model-based approach induced a systematic underprediction of actual default.

## 5.3. Regression framework: IRB loans issued before and after the event

In this section, we revisit potential selection concerns arising from the order in which IRB banks shift their loan portfolios from SA to IRB. As discussed in detail in Section 4, the selection of IRB portfolios was based on data quality and experience of the bank and should therefore result—if at all—in a downward bias of our coefficients. Nevertheless, we exploit time series variation in the date of loan issuance to remove any remaining doubts. To do so, we restrict ourselves to loans that actually use the IRB approach, and check whether the underestimation of actual default rates is greater for loans that were originated after the reform as compared with loans that were originated before the reform. In other words, we circumvent the selection concern by focusing on variation over time within the portfolio of IRB loans.

Specifically, we evaluate the performance of a sample of loans that were originated between 2005 and 2008, within two years before and after the reform. As our data is on the bank-firm level (and not on the contract level), we define the year of a loan issuance as follows: First, if a new bank-firm relationship is formed in a given year, it is clear that a new loan was originated in that year. Second, for existing bank-firm relationships, we assume that a new loan was granted if we see an increase of at least € 1.5 million (the lower bound for being reported in the credit register) and of at least 30 percent of the amount already outstanding in a given quarter.[27] Panel A of Figure 4 shows actual default rates and PD

[27] We focus on large increases in the outstanding loan amount of a given bank-firm relationship since most firms keep a checking account with their banks whose balances keep varying around a certain level quarter by quarter. Importantly, our results do not depend on the exact definition of a new loan issuance, i.e., we have tried different cutoff values and obtained similar results.

averages for these loans in 2009Q4. Loans originated in 2005 or 2006 (pre-reform) exhibit average PDs that are relatively close to actual default rates. In contrast, the actual default rate is considerably higher than the average PD for loans originated after the Basel II reform in 2007 or 2008 (post-reform), indicating a significant underestimation of credit risk for this set of loans.

Panel A of Figure 4 evaluates loan performance in 2009, which means that loans originated in different years differ in the time elapsed since their origination.[28] To rule out that the length of a specific relationship explains part of our findings in Panel A, we repeat the analysis using a different evaluation horizon. In particular, we evaluate loan performance four years after origination. That is, loans originated in 2005 are evaluated in 2009Q4, loans originated in 2006 are evaluated in 2010Q4, and so on. Hence, Panel B of Figure 4 evaluates the performance of all loans that still exist four years after their origination.[29] Average PDs are slightly higher than actual default rates for loans originated before the reform, and considerably lower than actual default rates for loans originated after the reform.

Table 4 provides regression results for Equation (3). As before, we use the estimation error as a dependent variable and start with a specification without any fixed effects for the set of loans introduced in Figure 4, Panel A. We find a significant difference between the two regimes, i.e., PDs for loans originated under Basel II are significantly more likely to underestimate actual default rates than PDs for loans originated before the reform. Column 2 shows that this result is robust to the inclusion of bank fixed effects, which means that the same bank more often underestimates the actual default rate for loans that were originated under Basel II. Finally, columns 3 and 4 repeat the estimations from the first two columns, using the set of loans with a four-year evaluation horizon from Figure 4, Panel B. Results are very similar.

Results in this section confirm that our findings in the previous section are not driven

[28] Evaluating loans in 2009 allows us to include loans that were originated within a two-year window around the reform, with the sample being relatively balanced between loans that were originated before and after the reform. The same test in 2010 yields similar results, but is less balanced since the share of loans originated before the reform is considerably lower.

[29] We also tried alternative evaluation horizons (three years, five years) and obtained similar results.

by the selection of IRB loan portfolios. We find a stronger underestimation effect for IRB loans that were originated after the reform as compared with IRB loans that were originated before the reform. While these loans differ in the time of origination, they find themselves within the same loan portfolios within IRB banks, i.e., those portfolios for which the new approach has already been implemented.

## 5.4. Further results

We further report some robustness tests to our main specification in Equation (2). Previously, we have given equal weight to all observations. However, one might argue that it is more important that IRB banks get PDs for larger loans right, as these loans are more important for the determination of overall required capital. If the underestimation effect is less severe for larger loans, it could be that on aggregate banks get required capital right. To test this, we report results for weighted regressions in columns 1 to 4 of Table 5, where we weight each observation by its loan size. Coefficients are somewhat smaller in these regressions as compared with the coefficients in the unweighted regressions (Table 3, columns 5 to 8). Nevertheless, they are still significant in most cases, indicating that the underestimation effect for IRB loans is also present if one considers the size of each loan.

Next, we use two alternative definitions for the dependent variable in the remaining columns of Table 5. First, in columns 5 to 8, we take the absolute value of the difference between the actual default dummy and the estimated PD for each loan as a left-hand-side variable. The coefficient for the IRB loan dummy is positive and significant in all cases. In previous regressions we investigated whether PDs for IRB loans are more likely to understate actual credit risk. By focusing on the absolute value of the estimation error, we treat an overestimation of actual default risk in the same way as an underestimation. Still, the regressions show that PD estimates for IRB loans are less precise than PD estimates for SA loans on average. Second, we focus only on loans that actually defaulted, i.e., on loans for which the difference between the actual default dummy and the PD is greater than 0, and set the difference for the remaining loans equal to 0. In this way, we check whether default risk for loans that actually defaulted was underestimated more by PDs for IRB loans. The

positive and significant coefficients for the IRB loan dummy in columns 9 to 12 show that this is indeed the case. PDs for loans that defaulted were on average lower if the IRB instead of the standard approach was used for the loan.

# 6. The overall impact of model-based regulation on capital charges and credit risk

So far, we have documented a systematic failure of PD models following the introduction of model-based capital regulation. Counter to the stated objective of improving risk management practices in the banking industry, model-based regulation has weakened the link between PDs and actual defaults. However, proponents of model-based regulation could argue that higher default rates associated with loans under IRB do not necessarily mean that aggregate credit risk has increased. Apart from the PD, risk-weights in the model-based approach also depend on loan-specific factors such as the loss given default (LGD), exposure at default (EAD), and the maturity (M) of the loan. Risk-weights in the advanced IRB approach will be lower the better the estimate on any of these parameters. Hence, the reform provides additional incentives for banks to invest into the quality of these parameters, for example by increasing the level of collateralization for IRB loans. Consequently, overall loan quality might have improved, despite the fact that default rates are higher for IRB loans. An assessment of the reform on overall credit risk and bank stability needs to take all loan-specific factors into account.

The data from the credit register allows us to address this issue. Apart from information on the PD, it also contains exposure-level information on risk-weighted assets and loan loss provisions. The risk-weight includes all firm-specific as well as loan-specific information relevant for a loan's regulatory capital charge. Loan loss provisions capture the losses incurred by a bank in case of default of a specific loan (see Section 3). Comparing regulatory risk-weights to actual losses for loans under SA and loans under IRB allows us to evaluate the reform's overall impact on credit risk.

A potential issue with a cross-sectional comparison of risk-weights and actual losses

of loans under different regulatory regimes could be that firms whose loans are still under SA are systematically different from firms whose loans have been shifted to IRB. To circumvent this issue, we focus on the sample of firms which have both SA loans and IRB loans from different IRB institutions and check whether regulatory risk weights and actual losses for these firms depend on the regulatory approach used for a specific loan. Average risk-weighted assets as well as loan loss provisions for loans to borrowers that have both IRB and SA loans at the same time are displayed in Figure 5. Average risk-weights for IRB loans are about 10 to 15 percent lower than average risk-weights for SA loans (see top panel of Figure 5). Thus, the regulatory capital banks are required to hold for loans to the same firm is considerably lower under IRB. However, the mid panel of Figure 5 shows that the ratio of aggregate loan loss provisions to loans is higher for the IRB portfolio as compared with the SA portfolio. Although banks have lower capital charges on average, they actually lose more money with loans under IRB.

To sharpen our analysis we re-estimate Equation (2), using the regulatory risk-weight or the ratio of loan loss provisions to loans as a dependent variable. To assess the impact on banks' overall capital charges and loan losses, we weight each observation by the amount of the respective loan. Table 6 provides estimation results for these regressions. We start with regulatory risk-weights at the time of loan origination.[30] Columns 1-4 show that the regulatory risk-weight for a loan to a specific firm is 5 to 10 percent lower when the loan is in the bank's IRB portfolio instead of the SA portfolio. Importantly, the inclusion of both firm and bank fixed effects allows us to control for heterogeneity across borrowers and lenders. As intended by the regulator, risk-weights for the same exposure are considerably lower under the IRB approach as compared with the standard approach. In the next step, we evaluate actual losses on the portfolios of loans included in the tests on regulatory risk weights. Although risk weights are lower for IRB loans, we find that actual loan loss provisions are—if anything—slightly higher for those loans have already been shifted to the new approach (Table 6, columns 5-8).

In a final test, we once more use variation in the timing of loan origination within

[30]For those lending relationships that already existed before 2008 we use the regulatory risk weight in 2008Q1, the first quarter for which this information is available.

banks' IRB portfolios to address potential selection concerns (see Sections 4 and 5.3). Specifically, we evaluate how the timing of loan origination affects actual losses on IRB loans; i.e., we re-estimate Equation (3), using the ratio of loan-loss provisions to loans as a dependent variable. As in Section 5.3, we evaluate loan performance either in 2009—which means that loans originated in different years differ in the time elapsed since their origination—, or four years after their origination—which means that loans originated in 2005 are evaluated in 2009, loans originated in 2006 are evaluated in 2010, and so on. We include the ratio of risk-weighted assets to loans at the time of loan origination as a control variable.[31] Results are presented in Table 7. We find that—independent of the evaluation horizon—actual losses on loans originated after the introduction of Basel II (i.e., in 2007 or 2008) are significantly higher than actual losses on loans originated before the reform, even as we control for differences in regulatory risk-weights and heterogeneities across banks.

The findings in this section suggest that banks experienced higher losses on portfolios under the model-based approach, although estimated PDs were considerably lower for these portfolios (see Section 5). Do these findings suggest that banks misjudged credit risk under the new regulation? Or were they aware of higher credit risk in portfolios under the model-based approach, and simply used the new regulation to economize on regulatory capital? Evidence on average interest rates indicates that it is likely that the latter holds. In Panel C of Figure 5, we report average interest rates for loans under SA and loans under IRB. While PD estimates were always considerably lower for loans under IRB as compared with loans under SA, we find exactly the opposite for the average interest rate. The fact that interest rates for IRB loans are considerably higher in all our sample years suggests that banks were aware of the actual risk involved with loans under the model-based approach.

[31] For those lending relationships that already existed before 2008 we use the risk weight in 2008Q1, the first quarter for which this information is available.

# 7. Bank lending around the introduction of model based regulation

In a final step, we try to identify potential winners and losers of the reform. While large banks had the ability to spread the compliance costs associated with the implementation of the model-based approach over a large portfolio of loans, small banks did not introduce the new regulation. Thus, banks that introduced IRB experienced a significant reduction in capital requirements for loans—both in absolute terms and relative to SA banks that did not introduce the new approach. In this section, we analyze whether the reform's differential impact on capital requirements had consequences for banks' lending behavior.

We have previously documented significantly lower PDs as well as lower average risk weights for loan portfolios under IRB. Figure 6 shows that, following the reform, banks that introduced the model-based approach expanded their lending to corporate borrowers in Germany.[32] Prior to the reform the development of aggregate loans was relatively similar for the two groups of banks. Following the reform, however, we see a sharp increase in aggregate loans for IRB banks, while the loans of SA banks remain relatively constant or even decline. To formalize the analysis, we collapse quarterly bank-level loans into single pre-event and post-event time periods by taking the average of the two years before and the two years after the reform and regress the change in this variable on a dummy that indicates whether the bank has introduced the model-based approach. Table 8 shows that IRB banks increased their lending by about 9 percent as compared with SA banks (column 1).[33] In column 2 we add several bank-level control variables (i.e., the pre-event logarithm of assets, ratio of equity to assets, ROA and bank ownership dummies), and find that larger banks, better capitalized banks, and more profitable banks increased their lending relatively more following the reform, while state banks reduced their lending relative to commercial banks and cooperative banks. The coefficient for the IRB bank dummy remains significantly positive. This

[32] For each group of banks—SA banks and IRB banks—we sum all loans in a given quarter to obtain aggregate loans. The figure shows the logarithm of aggregate loans—scaled by its value in 2007Q1—for SA and IRB banks (see Khwaja and Mian 2008 for a similar graphical illustration).

[33] According to Halvorsen and Palmquist (1980), the effect of dummy variables in semi-logarithmic equations is equal to $exp(\beta) - 1$.

finding is in line with results documented by Brun et al. (2013), who show that French banks increased their lending by similar magnitudes following the introduction of Basel II. To sum up, larger banks drastically expanded their lending relative to smaller banks, resulting in a further concentration of market shares in the market for corporate loans.

Under IRB, the capital charge for a specific loan depends on the estimated PD for that loan (see Section 2 for details). The PD is determined by the bank's internal risk model and depends on several hard information criteria. The better the hard information for a specific firm, the lower the PD for that firm, and the lower the capital charge for loans to that firm. Hence, we expect that IRB banks increase lending particularly to those firms where PDs are relatively low and hard information is relatively good. To test this assertion, we collapse the quarterly loan-level data into single pre-event and post-event time periods by taking the averages of the two years before and the two years after the reform, and regress the change in this variable on an interaction between the IRB bank dummy and the firm's PD. Formally, we run the following regression:

$$\Delta log(loans)_{ij} = \alpha_i + \alpha_j + D(IRB\ bank)_i \times Firm\ PD_j \times \gamma + \varepsilon_{ij}, \tag{4}$$

where $i$ denotes the individual bank, and $j$ denotes the individual firm. As a proxy for the goodness of hard information for a specific firm, we use the average PD banks report for that firm in 2008Q1, the first quarter for which this information is available (see Section 3). The lower this PD, the better the hard information the firm is able to provide to its banks. The variable is interacted with the dummy that indicates whether the bank adopted IRB during our sample period. Firm fixed effects are denoted by $\alpha_i$. Bank fixed effects are denoted by $\alpha_j$. To allow for potential correlation among changes in lending from the same bank we cluster standard errors at the bank level in all loan-level regressions. As we are trying to identify a supply side effect, it is important to control for a firm's demand for credit by including firm fixed effects (see Khwaja and Mian 2008). The 44,784 observations in the loan-level regressions correspond to all loans to firms with at least one loan from an IRB bank and at least one loan from an SA bank. Specifically, the tests show whether the same firm obtains relatively more loans from IRB banks as compared with SA banks, and

whether this effect depends on the hard information the firm is able to provide. Additionally, we include bank fixed effects that allow us to systematically control for heterogeneity across banks. That is, we test whether the same bank increases its lending relatively more to firms with good hard information, and whether this effect depends on whether the bank is an IRB bank or not.

Estimation results for Equation (4) are presented in Table 8, columns 3 to 6. We interact the IRB bank dummy with the firm PD variable and find that IRB banks increase lending to the same firm relatively more, but less so when the firm's PD is higher (column 3). This effect is robust to the inclusion of firm fixed effects in column 4, bank fixed effects in column 5, and both firm and bank fixed effects in column 6. Economically, the coefficients indicate that an increase of one standard deviation in *Firm PD* (0.031) induces a 1.2-2.5 percent smaller increase in loans from IRB banks. In line with our assertion, we find that IRB banks increase lending to the same firm significantly more than SA banks when the firm's PD is relatively low (i.e., when hard information is relatively good and capital charges are relatively low), but not when the firm's PD is relatively high (i.e., when hard information is relatively bad and capital charges are relatively high).[34]

Alternatively, we use different proxies for hard information from a matched sample that contains firm balance sheet information. While this sample is smaller than the original one, it has the advantage that balance sheet information is also available for 2006, the year before the reform. Results for these tests are presented in Table A.1 in the Appendix. We find that an increase of one standard deviation in the firm debt to asset ratio (0.202) induces a 5.9 to 8.3 percent smaller increase in lending from IRB banks. Similarly, an increase of one standard deviation in the logarithm of firm assets (1.428) induces an increase in loans from IRB banks that is about 5.7 percent larger. Finally, also a firm's profitability affects IRB banks lending reaction: An increase in one standard deviation of pre-event ROA (6.982) results in an increase in loans from IRB banks that is about 2.4 to 4.3 percent larger. All

[34] Ideally, we would have used the average PD in 2006Q4 in these test, i.e., a pre-reform value. Unfortunately, information on PDs becomes available in the credit register only in 2008Q1, which is why we have to rely on the assumption that these PDs are relatively sticky in most cases (see also below for additional tests with alternative hard information criteria from 2006).

these estimation results are robust to the inclusion of both firm and bank fixed effects.

Overall, we document that indeed the reform changed the quantity and the composition of bank lending. While the reform achieved a tighter link between estimated PDs and a bank's lending decision, the crucial link between PDs and actual default rates was lost in the process.

# 8. Discussion

In this paper, we use data from the German credit register to show that the introduction of model-based capital regulation under Basel II affected the validity of internal risk estimates. We find that risk estimates for loans under the model-based approach (IRB) systematically underestimate actual default rates, while there is no such effect for loans under the traditional approach. Moreover, the underestimation effect is worse for IRB loans that were originated after the reform as compared with loans that are subject to IRB but were originated before the reform. Based on this evidence, we argue that model-based capital regulation is unable to adequately capture the risk of financial institutions, as it changes banks' incentives and leads to a systematic failure of internal risk models. We further show that the introduction of model-based regulation induced lower aggregate capital charges, but higher actual losses. Thus, we conclude that the reform has failed to meet its ultimate objective of strengthening the soundness and stability of the international banking system.

Our findings can be explained by banks' overlending to borrowers that perform good on the dimensions used in banks' internal risk models. The overall riskiness of a borrower depends not only on the information used in a specific model, but also on unverifiable information that cannot be used for estimation purposes. Further, linking PDs to capital charges provides incentives for banks to exclude unfavorable information that cannot be verified by the regulator from the estimation of PDs. Therefore, model-based regulation fails to meet its stated objectives. While we cannot—and also do not want to—rule out additional problems associated with model-based regulation, our empirical findings strongly suggest that overreliance on borrowers with favorable value parameters for the PD models plays a crucial role

in explaining the failure of model-based capital regulation.

An alternative explanation for problems with model-based regulation would be a pure manipulation story: It could be that banks simply shift existing PDs downwards in order to economize on regulatory capital. Our time-series tests (i.e., the comparison of estimation errors for loans issued before and after the reform) can be seen as evidence against such an explanation: If banks simply manipulated PDs of existing borrowers after the reform (ex-post manipulation), the estimation error should be high for all IRB loans, irrespective of the date of loan origination. We have shown, however, that the estimation error is considerably larger for loans that were issued after the reform, where banks had incentives to lend to firms that score well on the dimensions used in the risk models (ex-ante manipulation).

Another explanation for our findings could be derived from the so-called 'Winner's Curse' problem. Firms tend to borrow from several banks at the same time and may shop for the lowest interest rate when applying for a new loan. The bank that estimates the lowest PD for a given borrower may offer the lowest interest rate to this borrower. Therefore, in equilibrium, the average PD assigned to a specific firm would be too low. While such a story is consistent with the systematic underestimation of PDs we documented, it rests on the assumption that banks link interest rates for loans to estimated PDs. We have shown that average interest rates for IRB loans tend to be higher than for SA loans, even though estimated PDs are lower for IRB loans. Thus, our findings are not consistent with a 'Winners Curse' explanation.

The regulation of bank capital requirements is one of the most controversial topics in today's world of banking. In recent years, a fundamental debate has evolved on whether current regulation is heading into the right direction. The financial system is complex in itself, and Basel II-type model-based regulation has added to this complexity by requiring the estimation of thousands of parameters for the determination of capital charges at a large bank. Basel III retains the trend towards more and more complex regulation and can, as expressed by Haldane (2011), easily be summarized as "more of the same – and better". Many have questioned whether such complex regulation actually benefits the financial system, and calls for simpler rules and guidelines are becoming louder in the regulatory community and

even among banks themselves. Our paper illustrates that complex regulation may fail to adequately capture credit risk, hence supporting the view that coarser regulation may have its benefits.

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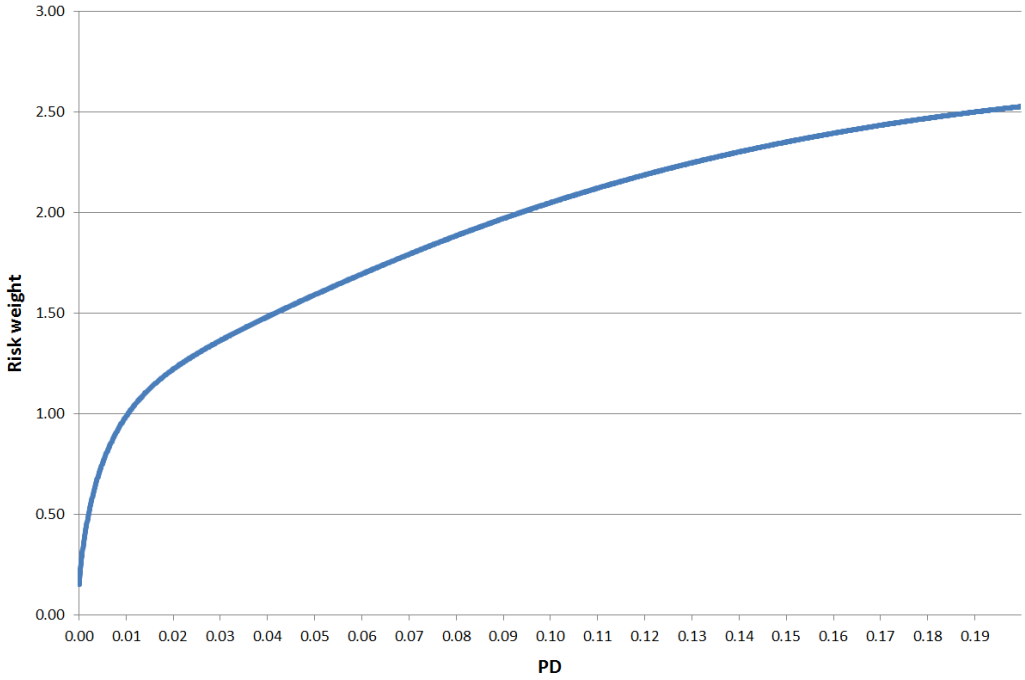



Figure 1: PDs and regulatory risk weights

The figure shows how estimated PDs map into regulatory risk-weights for loans in the corporate sector, assuming standard values for loss given default (45 percent) and loan maturity (2.5 years). The figure plots risk weights for loans to firms with a turnover larger than € 50 million. For loans to smaller firms, risk weights are multiplied with a correction factor depending on the exact amount of the turnover.

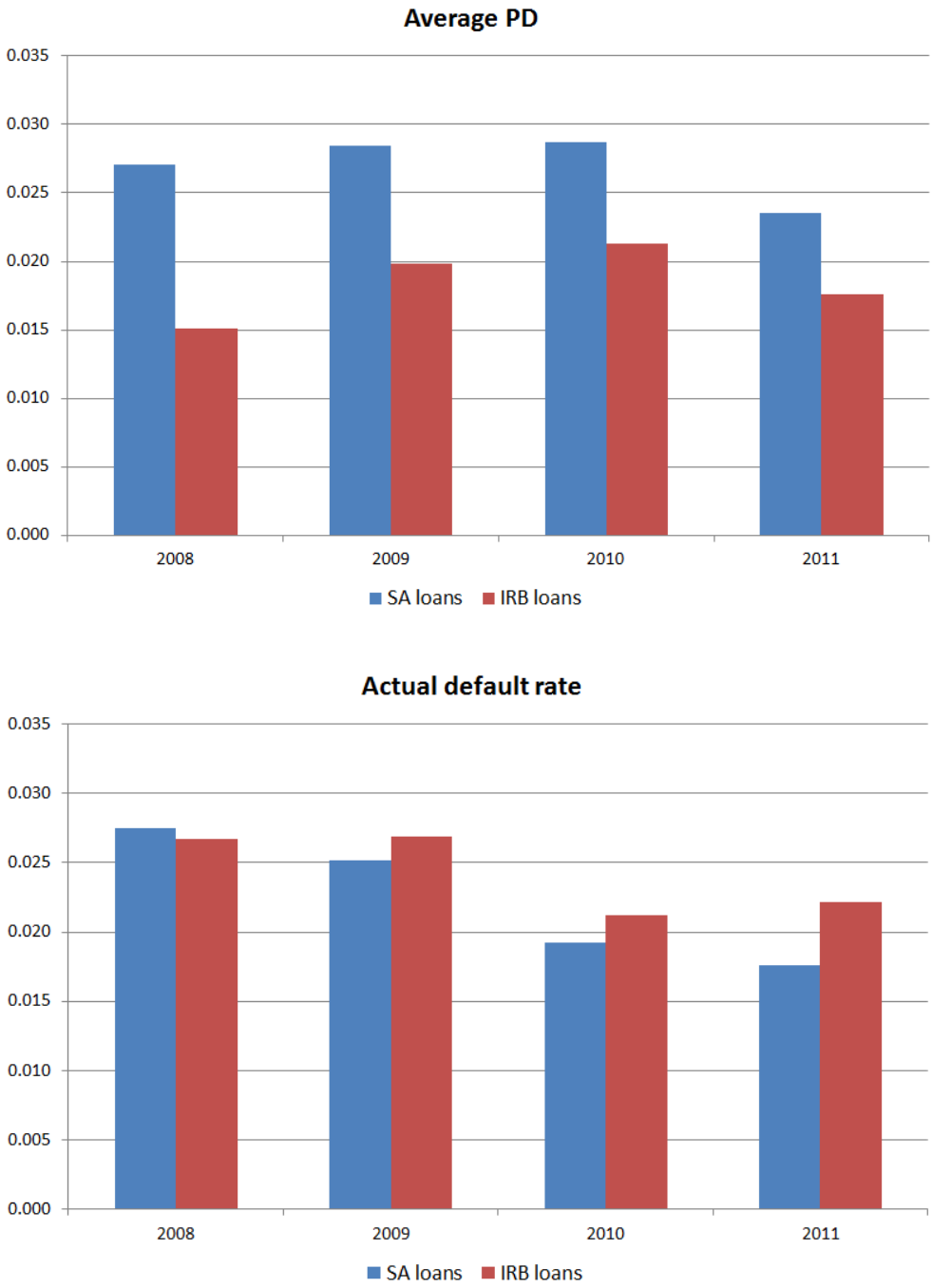



Figure 2: Average PDs and actual default rates

The figure shows average PDs and actual default rates for SA loans and IRB loans during the period from 2008Q1 to 2012Q2. For reasons of presentability we evaluate loan portfolios only once per year, at the end of each year (see Figure A.1 in the Appendix for the remaining quarters). The sample includes all loans that are not in default at the respective point in time. For the top panel, we calculate the averages of reported PDs for the respective portfolios of loans. For the bottom panel, we create a dummy that equals 1 for loans that default in the year following the respective quarter, and calculate the average of this dummy variable for the respective portfolios of loans.

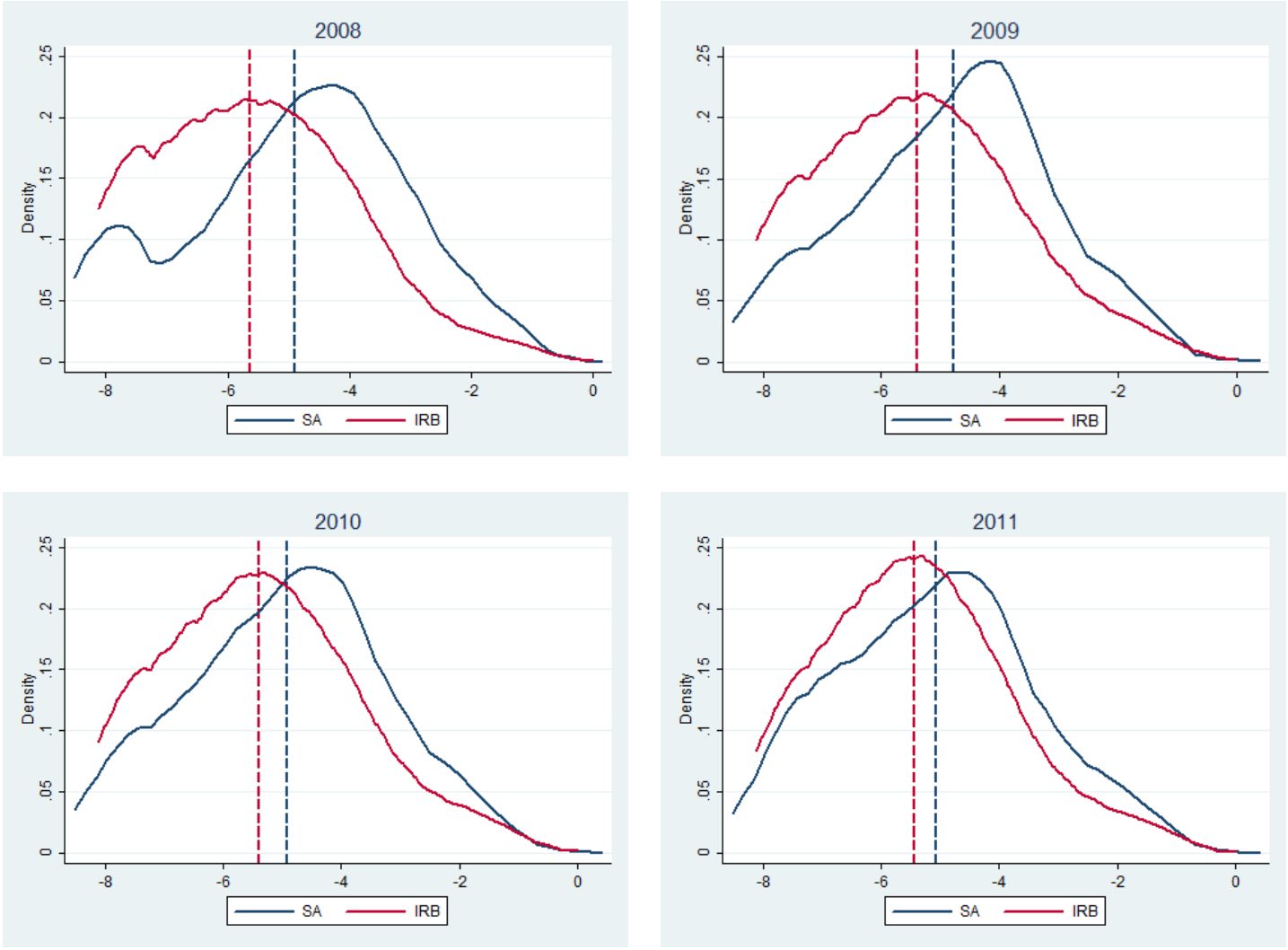



Figure 3: PD kernel densities

The figure shows Epanechnikov kernel densities for PDs at 2008Q4, 2009Q4, 2010Q4, and 2011Q4, respectively. PDs are reported in logarithms for reasons of presentability. The smoothing parameter in the density estimation is set to 0.4. The blue line corresponds to PDs for SA loans of IRB banks, the red line corresponds to IRB loans of IRB banks. Dashed vertical lines represent the respective mean of the distribution.

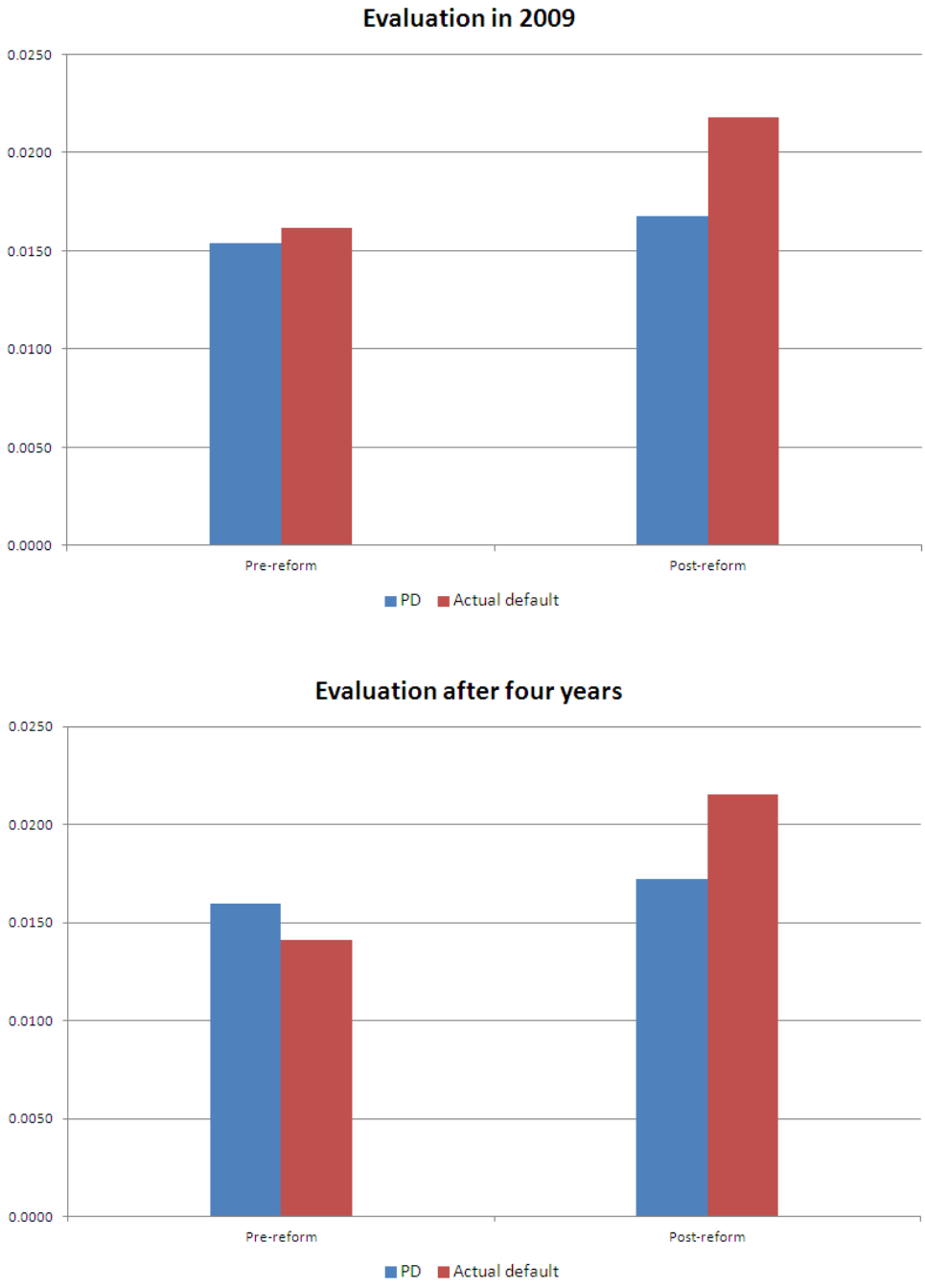



Figure 4: Average PDs and actual default rates by loan cohorts

The figure shows average PDs and actual default rates for loans under IRB that were originated in the years around the Basel II introduction, i.e., for bank-firm-relationships that did not exist before or that display a large increase (i.e., at least €1.5 million and at least 30 % of existing loan amount) in 2005 or 2006 (pre-reform), 2007 or 2008 (post-reform). In Panel A, all loans are evaluated in 2009Q4, whereas Panel B evaluates loans four years after their origination, i.e., loans originated in 2005 are evaluated in 2009Q4, loans originated in 2006 are evaluated in 2010Q4, and so on.

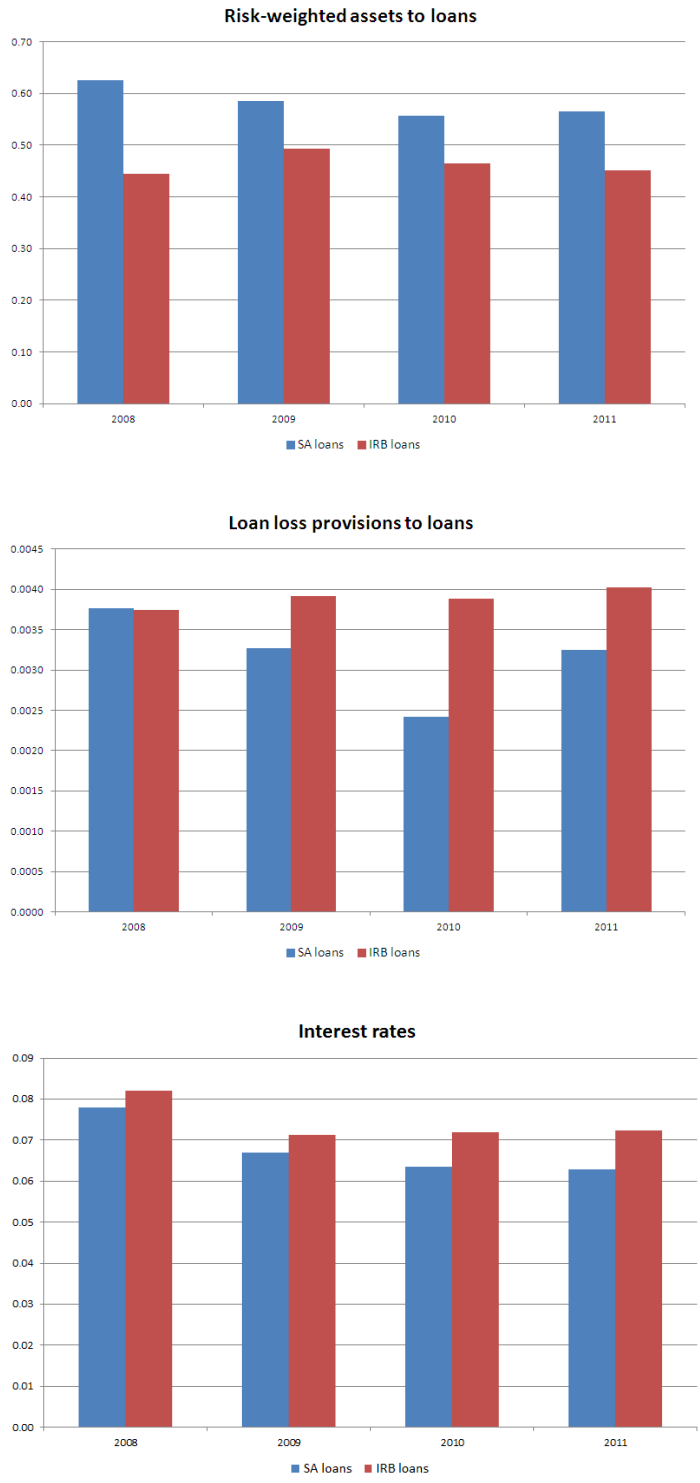



Figure 5: Risk weighted assets, loan loss provisions, and interest rates

The figure shows average risk-weighted assets to loans, the ratio of aggregate loan loss provisions to loans, and average interest rates for different points in time. The sample includes all loans to firms that have both IRB loans and SA loans from IRB institutions in the respective period.

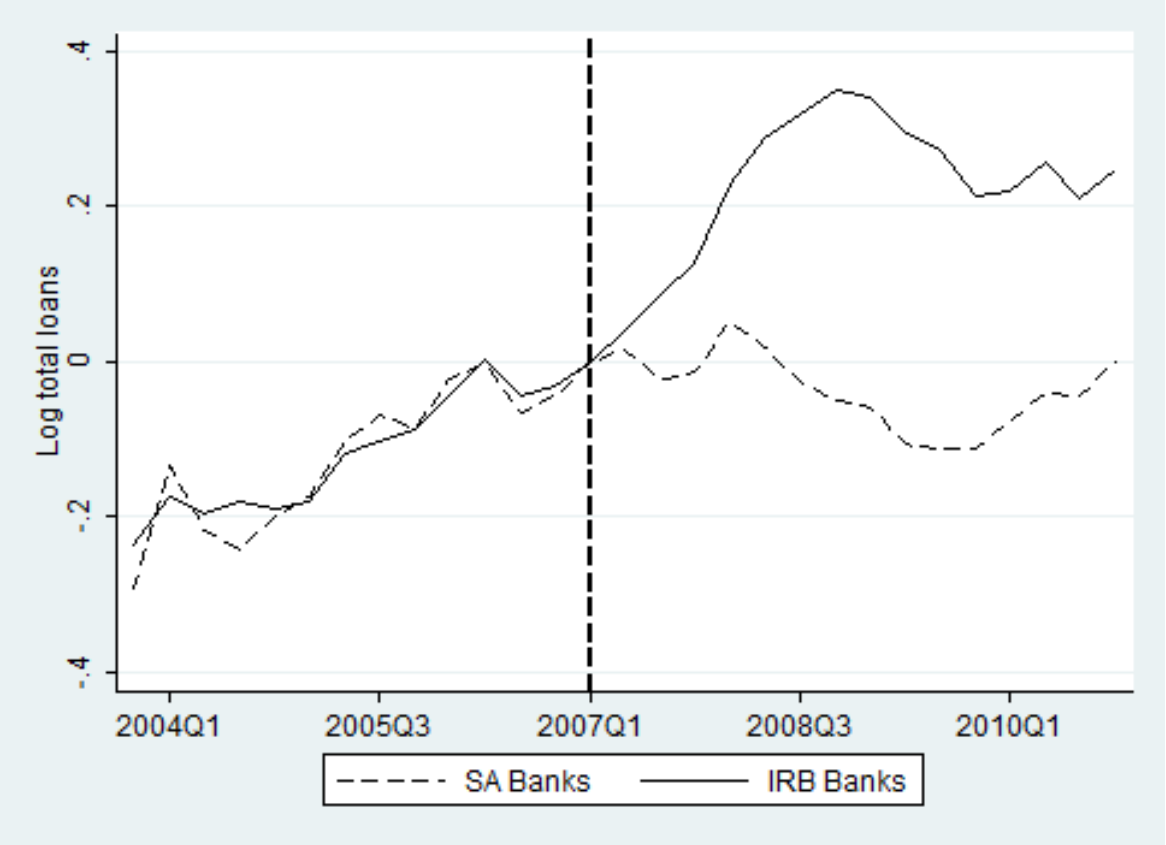



Figure 6: Aggregate lending around the Basel II introduction

The figure shows the development of aggregate lending in our sample for SA banks and IRB banks around the Basel II introduction in the first quarter of 2007. Aggregate numbers are obtained from the German credit register and calculated by summing all loans from the respective group of banks within a given quarter. Aggregate loans are standardized by their value in 2007Q1, and the figure shows the logarithm of this ratio (see Khwaja and Mian 2008 for a similar graphical illustration).

Table 1: Descriptives

Panel A: Bank descriptives

| | SA banks (1,558 banks) | | IRB banks (45 banks) | |
|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. |
| Bank assets (2006, in mn €) | 1,330 | 3,750 | 133,000 | 259,000 |
| Log bank assets (2006) | 20.158 | 1.162 | 24.196 | 1.937 |
| Bank equity ratio (2006) | 6.366 | 4.202 | 4.246 | 2.471 |
| Bank ROA (2006) | 0.680 | 0.464 | 0.673 | 0.584 |
| Bank type | | | | |
| ... commercial | 14.0 | – | 54.3 | – |
| ... state | 29.4 | – | 34.3 | – |
| ... cooperative | 56.7 | – | 11.4 | – |

Panel B: Loan descriptives

| | SA loans (81,961 loans) | | IRB loans (45,246 loans) | |
|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. |
| Δ log(loans) | 0.016 | 0.358 | 0.064 | 0.570 |
| PD | 0.026 | 0.060 | 0.018 | 0.061 |
| RWA to loans | 0.685 | 0.375 | 0.422 | 0.436 |
| LLP to loans | 0.438 | 0.286 | 0.478 | 0.305 |
| Interest rate | 0.068 | 0.040 | 0.075 | 0.042 |

Panel C: Firm descriptives

| | (5,961 firms) | |
|---|---|---|
| | Mean | S.D. |
| Firm PD | 0.022 | 0.031 |
| Firm assets (2006, in mn €) | 154 | 817 |
| Firm debt / assets (2006) | 0.343 | 0.202 |
| Log firm assets (2006) | 10.363 | 1.428 |
| Firm ROA (2006) | 7.909 | 6.982 |

Panel A shows descriptive statistics for the groups of SA and IRB banks. An IRB bank is defined as a bank that uses the internal ratings-based approach for some loans during our sample period, whereas an SA bank is defined as a bank that uses the Basel II standard approach in all its lending relationships. Panel B shows summary statistics for loans in the German credit register. Data are restricted to (a) loans that are larger than € 1.5 million (b) loans from commercial, state, or cooperative banks that are subject to the Basel II capital regulation (c) loans that have an observation both before and after the introduction of Basel II in 2007. Besides information on changes in lending around the reform the panel also includes information on loan interest rates, on the loan-specific ratio of risk-weighted assets to loans, of loan loss provisions to loans, and on the PD in 2008Q1, the first quarter for which this information is available. Panel C contains information on the firm level for a matched sample of 5,961 firms. Firm balance sheet information is obtained from Bundesbank's USTAN database.

Table 2: Estimation error—descriptives

Panel A: IRB banks, IRB loans

| | Observations | Actual default | PD | Actual default – PD |
|---|---|---|---|---|
| 2008 | 50,163 | 0.0267 | 0.0151 | 0.0116 |
| 2009 | 47,167 | 0.0269 | 0.0198 | 0.0071 |
| 2010 | 47,019 | 0.0212 | 0.0213 | -0.0001 |
| 2011 | 46,357 | 0.0222 | 0.0176 | 0.0046 |

Panel B: IRB banks, SA loans

| | Observations | Actual default | PD | Actual default – PD |
|---|---|---|---|---|
| 2008 | 22,751 | 0.0275 | 0.0270 | 0.0004 |
| 2009 | 23,426 | 0.0251 | 0.0284 | -0.0033 |
| 2010 | 21,130 | 0.0192 | 0.0287 | -0.0095 |
| 2011 | 18,894 | 0.0176 | 0.0235 | -0.0059 |

Panel C: IRB vs. SA

| | Difference in actual default | Difference in PD | Difference in difference |
|---|---|---|---|
| 2008 | -0.0008 | -0.0120 | 0.0112 |
| | [-0.6170] | [-31.7598] | [8.5746] |
| 2009 | 0.0018 | -0.0086 | 0.0103 |
| | [1.3766] | [-18.2768] | [7.9694] |
| 2010 | 0.0020 | -0.0074 | 0.0094 |
| | [1.7269] | [-14.2997] | [7.8497] |
| 2011 | 0.0046 | -0.0060 | 0.0106 |
| | [3.7342] | [-13.7121] | [8.5387] |

The table compares actual default rates with banks' estimated PDs in 2008Q4, 2009Q4, 2010Q4, and 2011Q4, respectively. Panel A includes all loans by IRB banks that were subject to the IRB approach in 2008Q1, the first period where this information is available. The column *Actual default* displays the mean of a dummy variable that is equal to 1 if the loan defaults in the year following the respective quarter. Loans that are already in default in the respective quarter are excluded. The column *PD* displays the average estimated one-year default rate for the same set of loans, and the column *Actual default - PD* displays the difference between the two. Panel B repeats the same analysis for all loans by IRB banks that were subject to the standard approach in 2008Q1. Panel C compares the two panels with each other by calculating—for each quarter—the difference between the values for IRB loans and for SA loans. The numbers in brackets are t-statistics.

Table 3: Estimation error—regressions

| | Dependent variable: Estimation error (actual default – PD) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| | 2008 | 2009 | 2010 | 2011 | 2008 | 2009 | 2010 | 2011 | 2008 | 2009 | 2010 | 2011 |
| D(IRB loan) | 0.0112*** | 0.0103*** | 0.0094*** | 0.0106*** | 0.0113*** | 0.0079*** | 0.0073*** | 0.0096*** | 0.0076*** | 0.0074*** | 0.0071*** | 0.0090*** |
| | (0.0014) | (0.0013) | (0.0013) | (0.0012) | (0.0021) | (0.0020) | (0.0019) | (0.0019) | (0.0028) | (0.0024) | (0.0025) | (0.0025) |
| Constant | 0.0004 | -0.0033*** | -0.0095*** | -0.0059*** | | | | | | | | |
| | (0.0011) | (0.0011) | (0.0010) | (0.0010) | | | | | | | | |
| Firm FE | NO | NO | NO | NO | YES | YES | YES | YES | YES | YES | YES | YES |
| Bank FE | NO | NO | NO | NO | NO | NO | NO | NO | YES | YES | YES | YES |
| Observations | 72,914 | 70,593 | 68,149 | 65,251 | 19,864 | 19,182 | 17,650 | 15,431 | 19,864 | 19,182 | 17,650 | 15,431 |
| R-squared | 0.0010 | 0.0009 | 0.0009 | 0.0011 | 0.6248 | 0.5910 | 0.5973 | 0.5861 | 0.6297 | 0.5989 | 0.6065 | 0.5914 |

The table shows loan-level regression results for 2008Q4, 2009Q4, 2010Q4, and 2011Q4, respectively. The dependent variable in all regressions is the difference between a dummy that indicates whether the respective loan defaults in the year following the respective period and the estimated PD of the loan. The sample includes all loans from IRB banks, where columns 5-12 are restricted to firms that have at least one IRB loan and at least one SA loan from an IRB bank. As we evaluate loans periodwise, there is one observation per bank-firm relationship in each regression. The dummy *D(IRB loan)* indicates the regulatory approach under which a specific loan was originated and is equal to 1 if the loan was issued under IRB. Columns 5-8 include firm fixed effects to control for heterogeneity across borrowers and columns 9-12 additionally includes bank fixed effects that control for heterogeneity across banks. 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 4: Estimation error by cohorts

| | Dependent variable: Estimation error (actual default – PD) | | | |
|---|---|---|---|---|
| | Evaluation in 2009 | | Evaluation after four years | |
| | (1) | (2) | (3) | (4) |
| Basel II | 0.0043*** | 0.0045*** | 0.0062*** | 0.0067*** |
| | (0.0010) | (0.0010) | (0.0013) | (0.0013) |
| Constant | 0.0008 | | -0.0018** | |
| | (0.0010) | | (0.0009) | |
| BANK FE | NO | YES | NO | YES |
| Observations | 67,015 | 67,015 | 49,382 | 49,382 |
| R-squared | 0.0002 | 0.0213 | 0.0005 | 0.0291 |

The table evaluates how the estimation error depends on the year of the loan origination. We include only loans that were originated in the years around the Basel II introduction, i.e., bank-firm-relationships that did not exist before or that display a large increase (i.e., at least €1.5 million and at least 30 % of existing loan amount) in the respective year. The dependent variable in all regressions is the difference between the dummy for actual default and the estimated PD for the loan. The dummy *Basel II* is equal to 1 if the loan was originated after the Basel II introduction (i.e., in 2007 or 2008) and equal to 0 if it was originated before (i.e., in 2005 or 2006). In columns 1 and 2, loans are evaluated in 2009Q4. In columns 3 and 4, loans are evaluated four years after their origination, i.e., loans originated in 2005 are evaluated in 2009Q4, loans originated in 2006 are evaluated in 2010Q4, and so on. 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 5: Estimation error—further results

| | Value weighted | | | | Absolute error | | | | Positive error | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| | 2008 | 2009 | 2010 | 2011 | 2008 | 2009 | 2010 | 2011 | 2008 | 2009 | 2010 | 2011 |
| D(IRB loan) | 0.0087** | 0.0053*** | 0.0045*** | 0.0068*** | 0.0040** | 0.0030* | 0.0043** | 0.0098*** | 0.0077*** | 0.0054*** | 0.0058*** | 0.0097*** |
| | (0.0036) | (0.0019) | (0.0017) | (0.0020) | (0.0021) | (0.0018) | (0.0017) | (0.0018) | (0.0019) | (0.0017) | (0.0015) | (0.0017) |
| Firm FE | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Observations | 19,864 | 19,182 | 17,650 | 15,431 | 19,864 | 19,182 | 17,650 | 15,431 | 19,864 | 19,182 | 17,650 | 15,431 |
| R-squared | 0.6332 | 0.6583 | 0.5594 | 0.6543 | 0.6540 | 0.6463 | 0.6586 | 0.6334 | 0.6598 | 0.6379 | 0.6406 | 0.6142 |

The table shows further loan-level regression results for 2008Q4, 2009Q4, 2010Q4, and 2011Q4, respectively. Columns 1-4 provide weighted regression results, where the dependent variable is the same as in Table 3 and observations are weighted by the size of the respective loan. In column 5-8 the dependent variable is equal to the absolute value of the difference between the dummy for actual default and the estimated PD for the loan. In columns 9-12 the dependent variable is equal to the difference between the dummy for actual default and the estimated PD for the loan for positive values of this difference and set to 0 for negative values. As before, the sample includes all loans from IRB banks to firms that have at least one IRB loan and at least one SA loan from an IRB bank. Loans are evaluated periodwise, so that there is one observation per bank-firm relationship in each regression. The dummy *D(IRB loan)* indicates the regulatory approach under which a specific loan was originated and is equal to 1 if the loan was issued under IRB. All columns include firm fixed effects to control for heterogeneity across borrowers. 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 6: Risk-weighted assets and loan loss provisions

| | RWA to loans | | | | LLP to loans | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| | 2008 | 2009 | 2010 | 2011 | 2008 | 2009 | 2010 | 2011 |
| D(IRB loan) | -0.0970*** | -0.0704** | -0.0451*** | -0.0822*** | 0.0000 | 0.0007 | 0.0056* | 0.0064* |
| | (0.0166) | (0.0298) | (0.0154) | (0.0277) | (0.0014) | (0.0011) | (0.0032) | (0.0037) |
| Bank FE | YES | YES | YES | YES | YES | YES | YES | YES |
| Firm FE | YES | YES | YES | YES | YES | YES | YES | YES |
| Observations | 21,373 | 19,504 | 17,056 | 16,306 | 21,373 | 19,504 | 17,056 | 16,306 |
| R-squared | 0.4840 | 0.5389 | 0.5621 | 0.5270 | 0.6961 | 0.7869 | 0.6989 | 0.6624 |

The table shows loan-level regression results for 2008Q4, 2009Q4, 2010Q4, and 2011Q4, respectively. The dependent variable in columns 1-4 is the ratio of risk-weighted assets to loans, whereas the dependent variable in columns 5-8 is the ratio of loan loss provisions to loans in the respective quarter. The sample includes all loans from IRB banks, but is restricted to firms that have at least one IRB loan and at least one SA loan from an IRB bank. As we evaluate loans periodwise, there is one observation per bank-firm relationship in each regression. The dummy *D(IRB loan)* indicates the regulatory approach under which a specific loan was originated and is equal to 1 if the loan was issued under IRB. All columns include bank and firm fixed effects to control for heterogeneity across banks and across borrowers. Observations are weighted by the amount of the loan in the respective year. 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 7: Loan loss provisions by cohorts

| | LLP to loans | | | |
|---|---|---|---|---|
| | Evaluation in 2009 | | Evaluation after four years | |
| | (1) | (2) | (3) | (4) |
| Basel II | 0.0017*** | 0.0014*** | 0.0042*** | 0.0031*** |
| | (0.0006) | (0.0005) | (0.0008) | (0.0006) |
| RWA to loans ratio | 0.0029** | -0.0001 | 0.0011 | -0.0001 |
| | (0.0013) | (0.0013) | (0.0010) | (0.0004) |
| Constant | 0.0036*** | | 0.0040*** | |
| | (0.0012) | | (0.0011) | |
| Bank FE | NO | YES | NO | YES |
| Observations | 46,053 | 46,053 | 37,557 | 37,557 |
| R-squared | 0.0010 | 0.0154 | 0.0015 | 0.0269 |

The table evaluates how the ratio of loan loss provisions to loans depends on the year of the loan origination. We include only loans that were originated in the years around the Basel II introduction (2005–2008), i.e., bank-firm-relationships that did not exist before or that display a large increase (i.e., at least €1.5 million and at least 30 % of existing loan amount) in the respective year. In columns 1 and 2, loans are evaluated in 2009Q4. In columns 3 and 4, loans are evaluated four years after their origination, i.e., loans originated in 2005 are evaluated in 2009Q4, loans originated in 2006 are evaluated in 2010Q4, and so on. The dummy *Basel II* is equal to 1 if the loan was originated after the Basel II introduction (i.e., in 2007 or 2008) and equal to 0 if it was originated before (i.e., in 2005 or 2006). The ratio of risk-weighted assets to loans is included as a control variable. Observations are weighted by the amount of the loan in the respective year. 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 8: Lending around the reform

| Dependent variable: | Δ log(bank loans) | | Δ log(loans) | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| D(IRB bank) | 0.0867** | 0.1115** | 0.0562*** | 0.0511*** | | |
| | (0.0346) | (0.0505) | (0.0181) | (0.0193) | | |
| D(IRB bank) × Firm PD | | | -0.5740*** | -0.5519*** | -0.4529*** | -0.3951** |
| | | | (0.1473) | (0.1580) | (0.1434) | (0.1573) |
| Firm PD | | | -0.2615*** | | -0.2990*** | |
| | | | (0.0811) | | (0.0890) | |
| Log bank assets (2006) | | 0.0073 | | | | |
| | | (0.0086) | | | | |
| Bank equity ratio (2006) | | 0.0067* | | | | |
| | | (0.0039) | | | | |
| Bank ROA (2006) | | 0.0498** | | | | |
| | | (0.0239) | | | | |
| D(state bank) | | -0.0772** | | | | |
| | | (0.0355) | | | | |
| D(cooperative bank) | | 0.0461 | | | | |
| | | (0.0345) | | | | |
| Constant | 0.1901*** | -0.0411 | 0.0286*** | | | |
| | (0.0096) | (0.1856) | (0.0068) | | | |
| Firm FE | NO | NO | NO | YES | NO | YES |
| Bank FE | NO | NO | NO | NO | YES | YES |
| Observations | 1,603 | 1,547 | 44,784 | 44,784 | 44,784 | 44,784 |
| R-squared | 0.0015 | 0.0336 | 0.0041 | 0.2271 | 0.0402 | 0.2626 |

The table shows how aggregate bank- and loan-level lending changed around the reform. The dependent variable in columns 1 and 2 is the change in the logarithm of aggregate bank lending over the Basel II introduction in 2007Q1. For each bank, we calculate aggregate lending by summing all loans in a respective period. We then collapse all quarterly data for a given bank into single pre-event and post-event periods by taking the average of the two years before and the two years after the Basel II introduction. The dependent variable in the regressions above is the difference in the logarithm of these averages, so that there is one observation per bank. The dummy variable *D(IRB bank)* indicates whether the respective bank adopted the Basel II internal ratings-based approach during our sample period. Columns 3-6 show results on the loan level. For each bank-firm relationship, we collapse all quarterly data into single pre-event and post-event periods by taking the average of the two years before and the two years after the Basel II introduction. The dependent variable in the regressions above is the difference in the logarithm of these averages, so that there is one observation per bank-firm relationship. Data are restricted to (a) loans that are larger than € 1.5 million (b) loans from commercial, state, or cooperative banks that are subject to the Basel II capital regulation (c) loans that have an observation in both the pre- and the post-event period (d) loans to firms that have at least one loan from an SA bank and one loan from an IRB bank. Robust standard errors adjusted for clustering at the bank level are reported in parentheses. Note: * indicates statistical significance at the 10 % level, ** at the 5 % level and *** at the 1 % level.

# Appendix

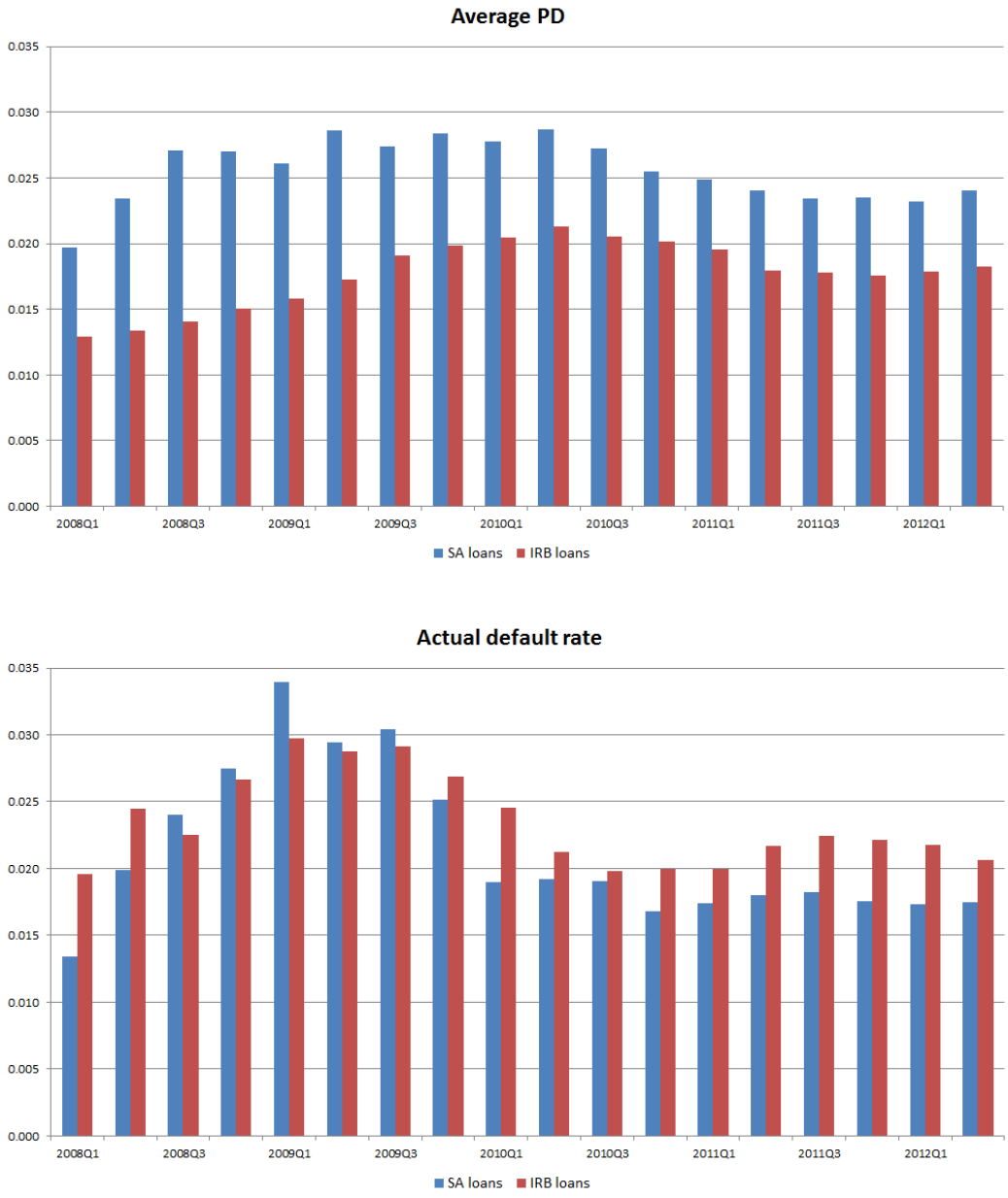



Figure A.1: Average PDs and actual default rates

The figure shows average PDs and actual default rates for SA loans and IRB loans during the period from 2008Q1 to 2012Q2. The sample includes all loans that are not in default at the respective point in time. For the top panel, we calculate the averages of reported PDs for the respective portfolios of loans. For the bottom panel, we create a dummy that equals 1 for loans that default in the year following the respective quarter, and calculate the average of this dummy variable for the respective portfolios of loans.

Table A.1: Lending around the reform—further results

| | Dependent variable: Δ log(loans) | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| D(IRB bank) × Firm debt / assets (2006) | -0.4276*** | -0.3020*** | | | | |
| | (0.0759) | (0.0683) | | | | |
| D(IRB bank) × Log firm assets (2006) | | | 0.0391*** | 0.0374*** | | |
| | | | (0.0101) | (0.0117) | | |
| D(IRB bank) × Firm ROA (2006) | | | | | 0.0060*** | 0.0034* |
| | | | | | (0.0021) | (0.0018) |
| D(IRB bank) | 0.1609*** | | -0.4580*** | | -0.0239 | |
| | (0.0299) | | (0.1132) | | (0.0304) | |
| FIRM FE | YES | YES | YES | YES | YES | YES |
| BANK FE | NO | YES | NO | YES | NO | YES |
| Observations | 8,411 | 8,411 | 8,735 | 8,735 | 8,748 | 8,748 |
| R-squared | 0.3015 | 0.3659 | 0.3245 | 0.3880 | 0.3138 | 0.3784 |

The table shows how loan level lending changed over the Basel II introduction. For each bank-firm relationship, we collapse all quarterly data for into single pre-event and post-event periods by taking the average of the two years before and the two years after the Basel II introduction. The dependent variable in the regressions above is the difference in the logarithm of these averages, so that there is one observation per bank-firm relationship. Data are restricted to (a) loans that are larger than € 1.5 million (b) loans from commercial, state, or cooperative banks that are subject to the Basel II capital regulation (c) loans that have an observation in both the pre- and the post-event period (d) loans to firms that have at least one loan from an SA bank and one loan from an IRB bank. We use a matched sample that includes firm balance sheet information from Bundesbank's USTAN database. Robust standard errors adjusted for clustering at the bank level are reported in parentheses. Note: * indicates statistical significance at the 10 % level, ** at the 5 % level and *** at the 1 % level.