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Back to the roots of internal credit risk models: Does risk explain why banks' risk-weighted asset levels converge over time?

Victoria Böhnke
(Deutsche Bundesbank and University of Münster)

Steven Ongena
(University of Zürich, Swiss Finance Institute, KU Leuven, NTNU Business School and CEPR)

Florentina Paraschiv
(Zeppelin University and NTNU Business School)

Endre J. Reite
(NTNU Business School)

Deutsche Bundesbank, Wilhelm-Epstein-Straße 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-0

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

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Non-technical summary

Research Question

The Basel Committee on Banking Supervision (BCBS) defined two distinct methodologies for calculating banks' capital requirements for credit risk. Based on a thorough assessment of the asset composition of banks' balance sheets and their business models, the regulatory purpose of the more risk-sensitive *internal ratings-based* (IRB) *approach* is to map differences in bank risks more adequately than with the *standardized approach*. Yet, we observe a downward convergence of their risk-weighted asset (RWA) densities over time. Complying with incentives to reduce their RWAs to meet the increased minimum capital requirements, banks may use risk-mitigation or opportunities for regulatory arbitrage. The pivotal question in this context is, if actual risk explains why banks' RWA densities converge over time.

Contribution

Our main contribution to the literature is twofold. First, we contribute to the current debate on unintended side effects of using the IRB approach. Second, we provide initial insights into the dynamic evolution of banks' RWA densities. Unlike previous literature, our study additionally considers differences in banking regulation and supervision across countries based on data taken from the World Bank's Bank Regulation and Supervision Survey. Based on a country grouping, our study reveals that risk does not fully explain why RWA densities converge over time.

Results

We demonstrate that RWA density convergence cannot be entirely explained by differences in bank size, loss levels, country risk, and/or time of IRB implementation. Banks in high-risk countries or in countries with less strict regulation and/or supervision reduce their RWA densities more than other banks. Conversely, banks facing strict regulation and/or supervision have roughly constant or slightly increasing RWA densities over time. Especially in high-risk countries, RWA densities seem to underestimate banks' actual economic risk. Hereby, we reveal that risk does not fully explain RWA density convergence. Thus, the IRB approach enables regulatory arbitrage, whereby authorities may only enforce strict supervision on capital requirements if they do not jeopardize bank existence.

Nichttechnische Zusammenfassung

Fragestellung

Der Baseler Ausschuss für Bankenaufsicht (BCBS) definiert zwei unterschiedliche Methoden zur Berechnung der Eigenkapitalanforderungen für das Kreditrisiko. Basierend auf einer detaillierten Beurteilung der Zusammensetzung der Bilanzen und Geschäftsmodelle der Institute besteht das regulatorische Ziel des risikosensitiveren *auf internen Ratings basierenden* (IRB) *Ansatzes* darin, Unterschiede in den Risiken der Banken adäquater abzubilden als mit dem *Kreditrisikostandardansatz*. Es ist jedoch eine Abwärts-Konvergenz ihrer risikogewichteten Aktiva(RWA)-Dichten im Zeitverlauf zu beobachten. Da aufgrund gestiegener Mindesteigenkapitalanforderungen Anreize zur RWA-Reduzierung bestehen, ist anzunehmen, dass die Institute entweder ihre Risiken reduzieren oder Möglichkeiten für regulatorische Arbitrage nutzen. Die zentrale Frage ist, ob das tatsächliche Risiko erklärt, warum die RWA-Dichten der Banken im Zeitverlauf konvergieren.

Beitrag

Unser Hauptbeitrag zur Literatur umfasst die folgenden beiden Aspekte. Erstens tragen wir zur aktuellen Diskussion über unbeabsichtigte Nebeneffekte bei der Anwendung des IRB-Ansatzes bei. Zweitens geben wir erste Einblicke in die dynamische Entwicklung der RWA-Dichten der Banken. Anders als in der bisherigen Literatur berücksichtigt diese Studie zusätzlich länderübergreifende Unterschiede in der Bankenregulierung und -aufsicht basierend auf Daten der Weltbank-Umfrage zur Regulierung und Aufsicht der Banken. Auf Basis einer Ländergruppierung zeigt diese Studie, dass Risiko nicht vollständig erklären kann, warum die RWA-Dichten im Zeitverlauf konvergieren.

Ergebnisse

Die Ergebnisse dieser Studie zeigen, dass die Konvergenz der RWA-Dichte nicht vollständig durch Unterschiede in der Bankgröße, der Verlusthöhe, dem Länderrisiko und/oder dem Zeitpunkt der IRB-Implementierung erklärt werden kann. Banken in risikoreichen Ländern oder in Ländern mit einer weniger strikten Regulierung und/oder Aufsicht reduzieren ihre RWA-Dichten stärker als andere Institute. Umgekehrt gilt vor allem in Ländern mit strenger Regulierung und/oder Aufsicht, dass Institute im Zeitverlauf annähernd konstante oder leicht ansteigende RWA-Dichten aufweisen. Insbesondere in risikoreichen Ländern scheinen RWA-Dichten das tatsächliche ökonomische Risiko der Banken zu unterschätzen. Hiermit zeigen wir, dass das Risiko die Konvergenz der RWA-Dichten nicht vollständig erklärt. Der IRB-Ansatz ermöglicht somit regulatorische Arbitrage, bei der Regulierungsbehörden eine strikte Aufsicht der Eigenkapitalanforderungen nur dann durchsetzen würden, wenn sie die Existenz der Banken nicht gefährden.

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Victoria Böhnke
Deutsche Bundesbank; University of Münster

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University of Zürich; Swiss Finance Institute; KU Leuven; NTNU Business School; CEPR

Florentina Paraschiv
Zeppelin University; NTNU Business School

Endre J. Reite
NTNU Business School

*Contact address: Deutsche Bundesbank, P.O. Box 10 06 02, 60006 Frankfurt am Main, Germany. Phone: +49 (0)69 9566 11949. E-Mail: victoria.boehnke@bundesbank.de. We are grateful to two anonymous reviewers, an anonymous associate editor, and Thorsten Beck (the editor) for helpful comments and suggestions. We also thank participants of the 2020 NTNU Business School Conference, the 2021 PhD Workshop sponsored by Unicredit, the 2021 NTNU PhD Workshop in Banking and Finance, the 2021 European Financial Management Association Annual Meeting, the 2021 Annual Meeting of the German Finance Association, the 10th Workshop Banks and Financial Markets, the 2021 Australasian Finance and Banking Conference, the 2022 ZU-UDE Workshop in Finance, and seminar participants at the University of Münster and at Deutsche Bundesbank, as well as Giulio Anselmi, Horst Bienert, Ricardo Cabral, Gerardo Ferrara, Thomas Gehrig, Andre Horovitz, Giuliano Iannotta, Björn Imbierowicz, Rüdiger Kiesel, Michael Koetter, Ouarda Merrouche, Alice Mladenka, Rouven Möller, Thilo Pausch, Andreas Pfingsten, Martin Ruckes, Christoph Schneider, André Uhde, and Giacomo Nocera for helpful comments and suggestions. We are grateful to Deutsche Bundesbank for financial support for the data collection process. The views expressed in this paper are those of the authors and do not necessarily represent those of the Deutsche Bundesbank or the Eurosystem. This research is partially funded by the Centre for Banking and Finance at NTNU Business School. Ongena acknowledges financial support from ERC ADG 2016 - GA 740272 lending. A supplementary online appendix is available at https://www.bundesbank.de/dp-en/2024-02-appendix.

Abstract

The internal ratings-based (IRB) approach maps bank risk profiles more adequately than the standardized approach. After switching to IRB, banks' risk-weighted asset (RWA) densities are thus expected to diverge, especially across countries with different supervisory strictness and risk levels. However, when examining 52 listed banks headquartered in 14 European countries that adopted the IRB approach, we observe a downward convergence of their RWA densities over time. We test whether this convergence can be entirely explained by differences in the size of the banks, loss levels, country risk, and/or time of IRB implementation. Our findings indicate that this is not the case. Whereas banks in high-risk countries with less strict regulation and/or supervision, reduce their RWA densities, banks elsewhere increase theirs. Especially for banks in high-risk countries, RWA densities seem to underestimate banks' economic risk. Hence, the IRB approach enables regulatory arbitrage, whereby authorities may only enforce strict supervision on capital requirements if they do not jeopardize bank existence.

Keywords: Capital regulation, credit risk, internal ratings-based approach, regulatory arbitrage, risk-weighted assets

JEL classification: G21, G28.

1 Introduction

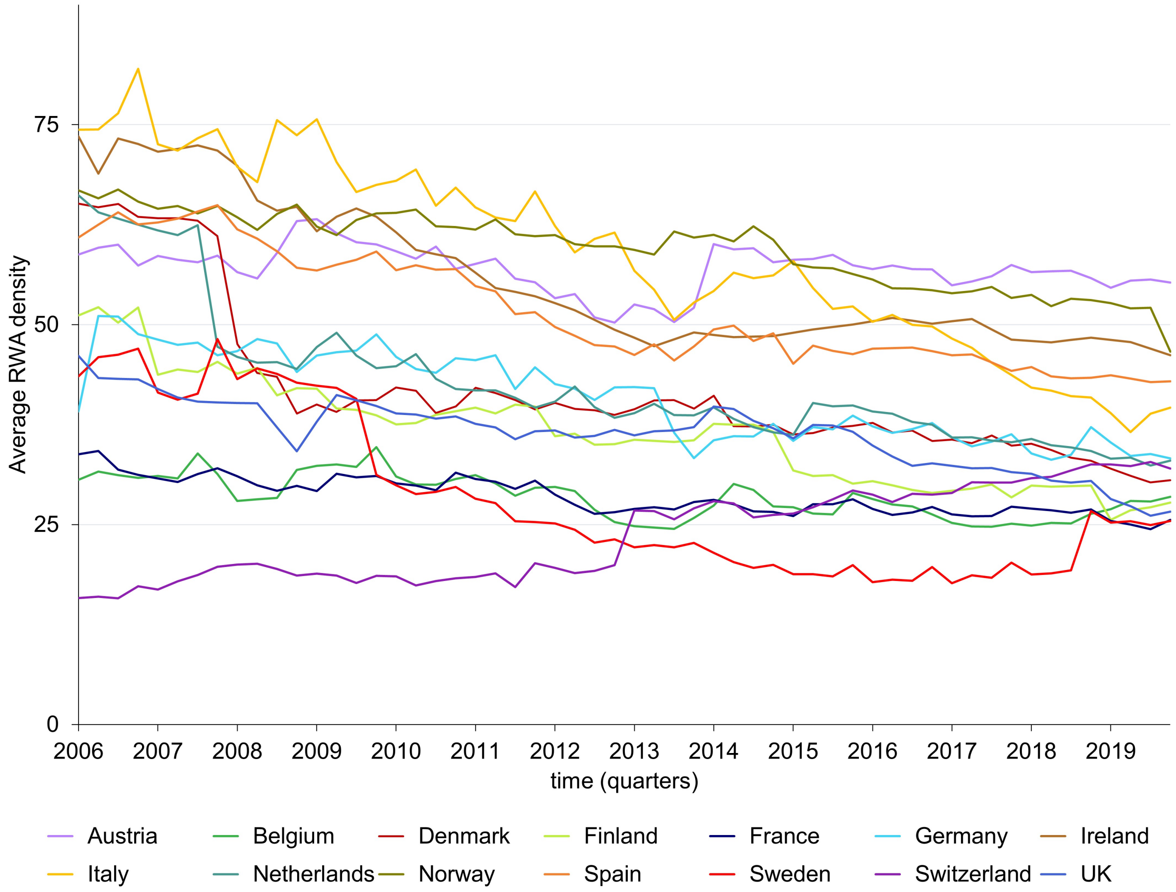
The Basel Committee on Banking Supervision (BCBS) defined two distinct methodologies for calculating banks' capital requirements for credit risk. Banks relying on the less risk-sensitive *standardized approach* use external credit assessments based on a predefined classification system. The regulatory purpose of the more risk-sensitive *internal ratings-based* (IRB) *approach* is to map differences in bank risks more adequately than with the standardized approach, based on a thorough assessment of the asset composition of banks' balance sheets and their business models. Intuitively, differences across banks should lead to higher dispersion in risk-weighted asset (RWA) estimations than obtained when employing the standardized approach (e.g., BCBS, 2013). Complying with incentives to reduce their RWAs to meet the increased minimum capital requirements, banks may use risk-mitigation or opportunities for regulatory arbitrage.

Calculated as the banks' RWAs over total assets, the RWA density provides a measure of the average riskiness of banks' assets (e.g., Mariathasan and Merrouche, 2014). As credit RWAs usually represent by far the largest share of total RWAs, they are commonly used in this context (e.g., Berg and Koziol, 2017). An increase in the RWA density shows that the overall quality of banks' assets deteriorated from the regulatory perspective. This increase may arise as assets with higher risk substitute lower-risk assets, without any change in the corresponding risk weight factors. Accordingly, a decrease in banks' RWA density would indicate that the average assets' risk profile improved. Alternatively, these changes in RWA density may be due to national regulations influencing RWA calculations. Countries' regulatory authorities impose regulations that set a soft or hard minimum capital requirement which translates in a lower bound on banks' RWA density. Whereas a capital ratio may mask different risk levels or measurement approaches, changes in RWA densities reflect gradual changes in banks' asset composition, the macroeconomic situation, and the regulatory and supervisory framework (Le Leslé and Avramova, 2012).

Whereas previous studies have focused on the heterogeneity of RWA densities across banks and jurisdictions (e.g., Mariathasan and Merrouche, 2014; Montes, Artigas, Cristófoli, and San Segundo, 2018), changes in RWA densities over prolonged time-periods across countries with different risk profiles and supervisory strictness have not yet been explored. Research on implications of internal credit risk models on banks' RWAs largely focus on two questions. First, are capital requirements sufficiently risk-sensitive to ultimately achieve a strong and resilient banking system (e.g., Barakova and Palvia, 2014; Ahnert, Chapman, and Wilkins, 2020)? Second, are the resulting RWA levels consistent across banks and jurisdictions (e.g., Mariathasan and Merrouche, 2014; Berg and Koziol, 2017)? In this context prior research also acknowledges differences in national banking supervision, domestic credit supply, as well as the economic conditions (Agarwal, Lucca, Seru, and Trebbi, 2014; Gropp, Mosk, Ongena, Simac, and Wix, 2023). However, their effects on the dynamic temporal development of banks' RWA density reductions are not discussed at all.

We therefore investigate quarterly data of 52 listed banks headquartered in 14 European countries that adopted the IRB approach between Q1/2007 and Q4/2019. We aim to shed light on why RWA densities converge over time across countries and banks despite their different risk profiles, as shown in Figure 1. We therefore control for several factors that could explain convergence such as country risk, bank size, portfolio composition, loan loss provisions, and profitability to explore if these factors explain a convergence. Further, we explore differences in the RWA levels, by grouping banks based on their sovereign risk and regulatory and supervisory strictness.

Figure 1: Country average risk-weighted asset density of banks using the internal ratings-based approach over time.



Notes: This figure illustrates the development of the country quarterly mean of internal ratings-based (IRB) approach banks' risk-weighted asset (RWA) densities. Figures A.4 and A.5 in the Internet Appendix present the RWA density development for each bank separately.

To the best of our knowledge, we are the first to introduce a country grouping which accounts for both sovereign credit risk and the national levels of banking regulation and supervision. Second, we employ a cross-sectional setting to analyze the development of RWA densities relative to the quarter of the switch across these country groups. Third, we estimate a panel model to examine the factors impacting the changes in RWA density over time.

Our results reveal that RWA densities of banks using the IRB approach converge downwards over time. The mean RWA density decreases from 49.77 in 2007 to 35.47 in 2019 and the corresponding standard deviation decreases from 18.70 to 13.18. We find that factors like bank profitability, equity capital, and the countries' credit supply are significant in explaining variation in RWA density (e.g., Ferri and Pesic, 2017; Montes et al., 2018). Moreover, countries in the same risk- or regulatory strictness group share some common traits. In countries with high country risk, banks' RWA density only slightly decreases or even increases with the adoption of the IRB approach, still closely reflecting the high country risk. Yet, the initial change is followed by a gradual decrease which occurs at a higher pace than in most other countries. Apart from risk, we additionally take into account the countries' regulatory and supervisory strictness. In countries with less strict regulations, we document a significant initial reduction of RWA density upon adopting the IRB approach, followed by further gradual decreases over time. In contrast, countries with strict supervision reduce their RWA densities to a smaller extent after the switch to the IRB approach. Most notably, in countries with strict supervision, banks' RWA densities subsequently remain largely stable and even increase in response to the tightening of regulations. Furthermore, we shed light on the inconsistencies in banking regulation and supervision across countries (e.g., Agarwal et al., 2014; Gropp et al., 2023) and show how national differences distort the validity of RWA densities, representing the key measure of regulatory risk (Berger, 1995; Vallascas and Hagendorff, 2013).

In line with the original regulatory intention, the IRB approach enables banks to calculate the required capital according to their individual risk exposure (BCBS, 2004). Prior studies emphasize the importance of risk sensitivity in capital regulation and indicate potential problems of insensitivity to risk (e.g., Barakova and Palvia, 2014; Colliard, 2019; Ahnert et al., 2020). However, RWAs of banks that use internal models are not reflecting the actual economic risk, suggesting a reduction beyond the amount intended by the regulator (European Banking Authority (EBA), 2015a; Plosser and Santos, 2018; Colliard, 2019). With respect to Germany, Behn, Haselmann, and Vig (2022) provide evidence suggesting systematic underreporting of risk due to model-based regulation. We expand on this finding by investigating differences between banks' reported RWAs across Europe and show that there are undesired effects leading to differences in risk measurement between countries with different risk levels and differences in regulatory and supervisory strictness.

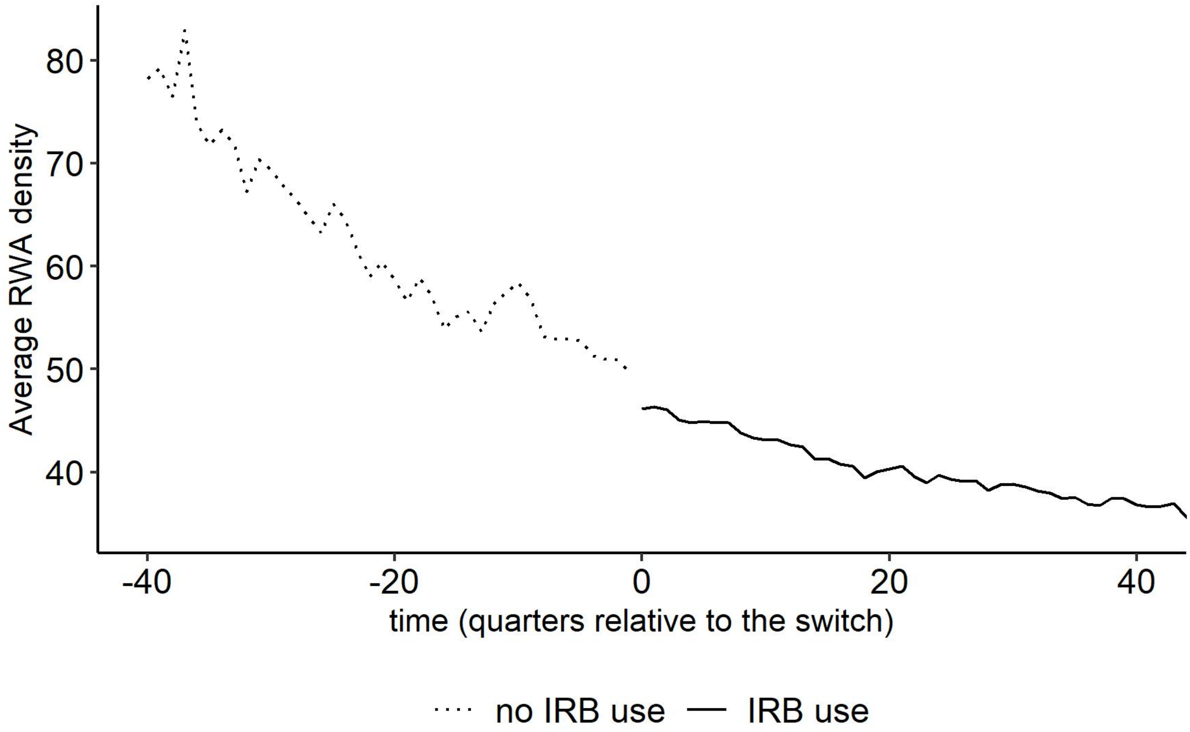
Generally, banks are mainly motivated to switch to the IRB approach if they can achieve lower RWA densities. Indeed, empirical studies show that after obtaining the approval to use the IRB approach, banks' RWA densities decrease (e.g., Mariathasan and Merrouche, 2014; Montes et al., 2018). On the one hand, the calculation procedure of the IRB approach is tailor-made and maps banks' individual risk profiles more adequately than the standardized approach but, on the other hand, it seems to allow certain leeway in RWA calculations. Indeed, prior studies argue that the IRB approach provides opportunities for regulatory arbitrage where banks reduce their regulatory capital without an analogous and adequate decrease in economic risk (e.g., Jones, 2000).

This is reflected by the substantial initial reduction in RWA density in all banks directly after the switch. Figure 2 illustrates the development of the mean RWA density relative to the quarter of IRB approval. While Mariathasan and Merrouche (2014) study the initial reduction in RWA densities at the quarter of the switch (gap between the dotted and the solid line), we shed light on the subsequent reduction (solid line).[1] Together with the illustration across the different country groups in the Internet Appendix, this figure highlights the importance to investigate (1) the long-term development of RWA densities,

[1] Moreover, Figure A.1 in the Internet Appendix shows the differences in RWA density development in different country groups.

and (2) the differences across countries with differences in risk, supervisory power, and regulatory stringency.

Figure 2: Bank average risk-weighted asset densities before and after IRB approval.

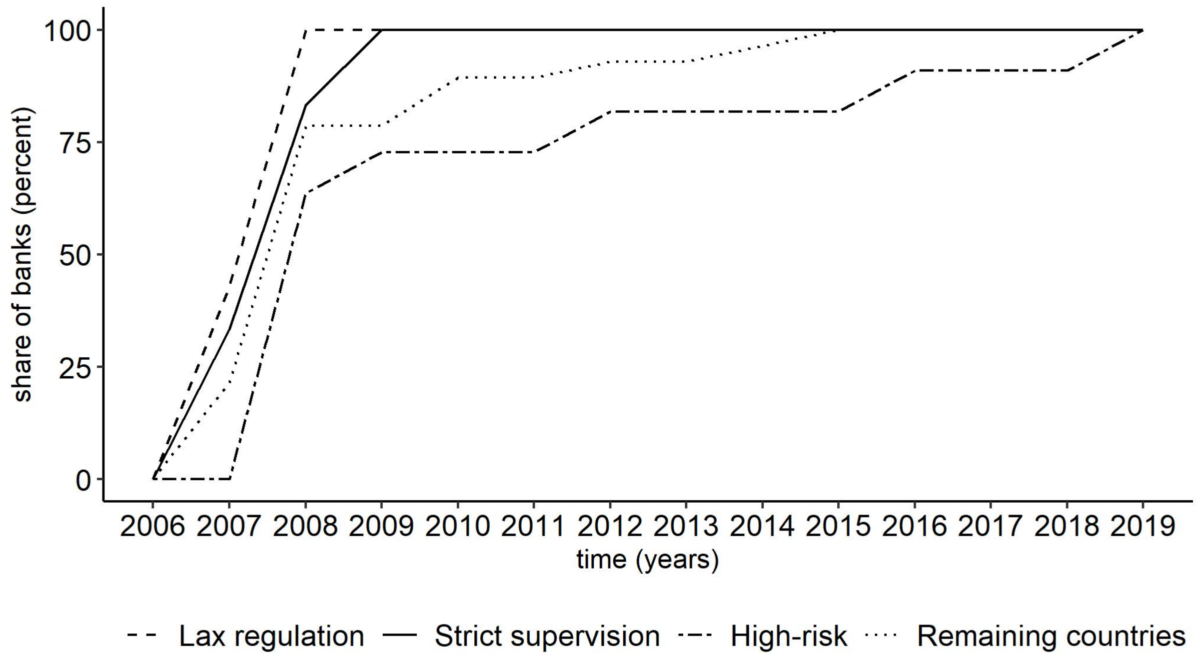


Notes: This figure illustrates the development of the quarterly mean risk-weighted asset (RWA) density relative to the quarter of approval $s = 0$.

In this context, the timing of IRB implemention plays a role as it may differ between differently regulated jurisdictions. Figure 3 shows the cumulative share of banks that have adopted the IRB approach over time. Most banks switch before 2009, while only some banks in high-risk countries or in the remaining countries adopt the IRB approach later during the sample period. Previous literature suggests that reduced capital requirements from using the IRB approach created incentives for larger banking organizations to switch to advanced IRB models to maintain competitivity (e.g., Berger, 2006). Moreover, larger institutions could create a competitive advantage in pursuing low-risk clients (e.g., Hakenes and Schnabel, 2011) by early adoption. As we focus on large banks, the timing of IRB implementation does not differ substantially between the banks in our data set.

Previous literature documents inconsistencies in the regulation and supervision of banks. Some studies show systematic differences in the strictness of supervision between banks under surveillance of the national supervisory authorities and banks under supranational supervision (e.g., Haselmann, Singla, and Vig, 2019; Colliard, 2020). Several studies document that supervisory authorities are lenient with potential bank failures (e.g., Brown and Dinç, 2011; Morrison and White, 2013; Walther and White, 2020). Reasons include political influence on the regulatory authorities and considerations on the competitiveness of domestic banks (e.g., Schoenmaker, 2012; Reinhardt and Sowerbutts, 2015).

Figure 3: Timing of IRB implementation across country groups.



Notes: This figure illustrates the cumulative share of banks that have implemented the internal ratings-based (IRB) approach over time.

To further explain the discretion of supervisory authorities, Gropp et al. (2023) focus on the introduction of supranational regulation at the national level. Gropp, Mosk, Ongena, and Wix (2019) show how banks increase their capital ratios through an RWA reduction. However, Gropp et al. (2023) reveal that this increase neither coincides with a corresponding increase in book equity nor adequate risk reduction. Gropp et al. (2023) also indicate how regulators allow for leeway in defining regulatory capital. Banks' ability to reduce their RWA densities should reflect economic outlooks as well as country- and bank-specific risks. From the regulatory perspective, authorities aim to limit this ability to redefine risk without a change in actual risk levels.

One possible alternative explanation is that an actual convergence in banks' portfolio allocations is the reason why RWA densities converge over time (e.g., Mariathasan and Merrouche, 2014; Greenwood, Stein, Hanson, and Sunderam, 2017; Hoshi and Wang, 2021). Bräuning and Fillat (2019) provide evidence that large banks' portfolio structures converge in response to US stress tests. Hoshi and Wang (2021) additionally mention the role of tighter regulations in this context. We take into account these aspects and show that they do not fully explain RWA density convergence over time.[2]

Further studies analyze the impact of model-based capital regulation on bank profitability (Ferri and Pesic, 2019; Mascia, Keasey, and Vallascas, 2019; Böhnke and Woyand, 2021). Beltratti and Paladino (2016) find that banks that are more aggressive in reducing their RWA densities subsequently have a lower return on equity and are more likely to raise new capital during a credit crisis. Banks can adjust to new capital levels by reducing

[2]Figure A.2 in the Internet Appendix illustrates banks' loan portfolio composition across country groups.

lending, or raising new capital. Further, banks with low profitability are more likely to reduce lending. Thus, regulators refrain from imposing stricter regulations on low profitability banks or when the real economy experiences low growth (Repullo and Suarez, 2013).

Our study relates directly to the literature on the effect of changes in capital requirements on bank credit supply (e.g., Hyun and Rhee, 2011; Brei, Gambacorta, and Von Peter, 2013; Han, Keys, and Li, 2018; De Jonghe, Dewachter, and Ongena, 2020; Fraisse, Lé, and Thesmar, 2020) and rests on an understanding of the real effects of increasing capital requirements. Ferri and Pesic (2020) suggest that high capital requirements reduce national credit supply with potential negative effects on medium-size banks. Moreover, Juelsrud and Wold (2020) show that banks react to higher capital requirements by reducing their average risk weights and document their influence on the real economy. With reference to the IRB approach, Behn, Haselmann, and Wachtel (2016) show that internal models increase the procyclicality of loan supply. We contribute to the current debate on unintended side effects of using the IRB approach and provide initial insights into the evolution of banks' RWA densities and reveal that risk does not fully explain why they converge over time.

Our findings become relevant in the wake of the relaxed financial regulations on minimum capital requirements and credit risk management intended to overcome Covid-19 crisis-related challenges to the banking system (EBA, 2020; EBA, 2021). In the absence of regulatory relaxations, higher probabilities of default in economic downturns lead to increasing RWA densities (Behn et al., 2016), which increases the burden on banks, with possible negative spillover effects on the economy. Thereby, authorities may only enforce strict supervision on capital requirements if they do not jeopardize bank existence. Disentangling the influence of country risk, different regulatory and supervisory strictness on banks' RWA densities is, thus, highly important to assess the effects of updated regulatory policies in times of crises.

The remainder of the paper proceeds as follows: We summarize stylized facts in Section 2. In Sections 3 and 4, we explain the empirical design and the methodology. Estimation results are discussed in Section 5, and Section 6 concludes.

2 Stylized facts

In this study, we focus on banks' RWA densities as they reflect gradual changes in banks' asset composition, the country-specific macroeconomic situation, and the regulatory and supervisory frame (Le Leslé and Avramova, 2012).[3] Even though there are some inconsistencies due to accounting differences across countries and over time and due to the RWAs calculation procedures (Arroyo, Colomer, García Baena, and González Mosquera, 2012), they relate to all bank exposures that are considered relevant from a regulatory perspective. Aiming at a level playing field in banking regulation, RWAs represent the most appropriate regulatory risk measure for the purpose of our study, as RWA calculations do not depend on the measure of capitalization or the banks' target regulatory capital ratio.

[3]More detailed stylized facts of RWA densities in banks are provided in Internet Appendix A.2.

Figure 1 illustrates the development of the countries' quarterly mean RWA density for the IRB banks. We observe a large dispersion between the countries' RWA densities at the beginning of our observation period which, however, converge to a similar level over time.[4] Most banks are observed to switch shortly after the adoption of the IRB approach becomes possible in their country.[5] To illustrate the RWA density development relative to the quarter of IRB approval, Table 1 provides an overview of average RWA densities across countries at the quarter of the switch, as well as five and ten years later. In contrast to the overall downward trend, we observe increasing RWA densities for banks in some countries between five and ten years after the switch.

Table 1: Average risk-weighted asset density per country.

	Average RWA density			**RWA density change (%)**	
Country	**Quarter of switch**	**5 years after switch**	**10 years after switch**	**5 years after switch**	**5-10 years after switch**
Austria	55.71	52.23	54.79	-6.25	4.91
Belgium	28.69	26.88	24.97	-6.33	-7.11
Denmark	47.58	39.43	35.12	-17.13	-10.92
Finland	33.53	30.46	36.70	-9.14	20.46
France	29.52	27.14	28.43	-8.09	4.75
Germany	44.38	42.93	35.14	-3.27	-18.14
Ireland	63.48	50.24	48.75	-20.87	-2.96
Italy	56.10	50.11	34.18	-10.68	-31.79
Netherlands	44.43	33.36	37.92	-24.92	13.67
Norway	62.94	58.17	54.00	-7.58	-7.17
Spain	60.54	45.77	43.76	-24.40	-4.41
Sweden	41.50	25.15	17.66	-39.39	-29.79
Switzerland	17.45	22.70	30.45	30.13	34.11
UK	40.21	36.14	31.37	-10.11	-13.20
Number of banks	**52**	**47**	**41**		
Average across banks	**46.13**	**40.30**	**36.86**	**-12.64**	**-8.54**

This table provides an overview of the development of average risk-weighted asset (RWA) densities per country after banks started to use the internal ratings-based approach. Comparable to the cross-sectional analysis, we calculate the average RWA density of each bank relative to the quarter of approval $s = 0$. As several banks switch later during our sample period, the number of available banks to calculate the average RWA density decreases.

We formally test the convergence of banks' RWA densities. First, we compare the standard deviation of the observations of the four quarters of 2007 to those of the four quarters of 2019. According to a simple pooled F-test they are significantly different.[6]

[4] Table A.3 in the Internet Appendix provides summary statistics of banks' RWA densities across years. Both mean and median values confirm the downward trend. In line with the convergence of RWA densities over time, the standard deviation of all banks' RWA densities per year gradually decreases across years. Moreover, the minimum values remain on a similar level, while the maximum values sharply decline, indicating convergence towards the lowest observed levels. For comparison purposes, Figure A.3 in the Internet Appendix illustrates the development of the countries' annual mean RWA density of banks using the standardized approach.

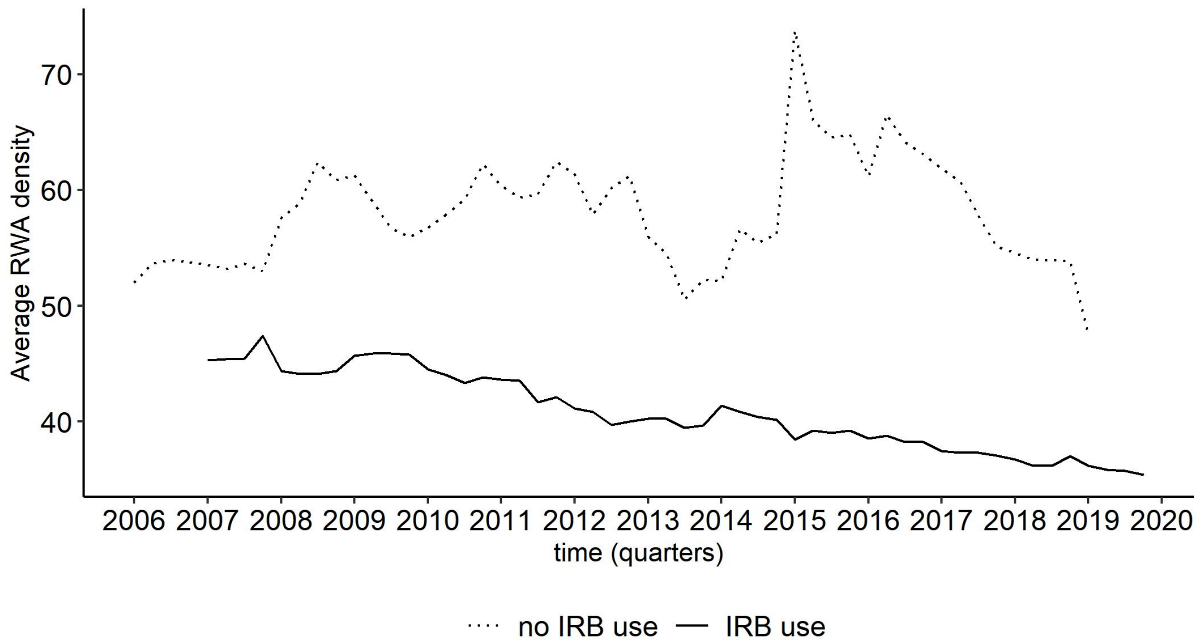
[5] Figures A.4 and A.5 in the Internet Appendix present the evolution of RWA densities for each bank and illustrate the time of the switches to the IRB approach for each bank.

[6] Figure A.6 in the Internet Appendix illustrates the quarterly mean and standard deviation of all banks' RWA densities over time.

Second, we estimate a panel model including country × quarter-fixed effects.[7] The results confirm the convergence and support our expectations with respect to the effects of the different country groups and patterns across quarters.

It is important to note that we observe decreasing RWA densities for banks using the IRB approach. Figure 4 compares the RWA density for banks using the IRB approach with those not using the IRB approach. While banks not using the IRB approach remain on a similar level, the IRB adoption reduces the RWA density over time.[8]

Figure 4: Bank average risk-weighted asset densities over time.



Notes: This figure illustrates the development of the quarterly mean risk-weighted asset (RWA) density over time.

The large differences between RWA densities at the beginning of our observation period may reflect the differing interpretations of the Basel II framework by banks and/or supervisory authorities, or may be due to different levels of supervisory power in the validation processes. As a response to the growing criticism on RWA heterogeneity (Arroyo et al., 2012; Vallascas and Hagendorff, 2013), the introduction of Basel III in 2010 or of the Single Supervisory Mechanism in the euro area in 2014 may have reduced the heterogeneity among banks over the sample period. Furthermore, the EU-wide stress testing exercises may have affected individual banks' behavior (Cornett, Minnick, Schorno, and Tehranian, 2020). Nevertheless, RWA densities should continue to reflect sovereign risks, as most banks' balance sheets contain primarily home country assets. From a regulatory perspective, it should not be possible to eliminate the country-specific risk factor.

[7]Appendix A.6 summarizes the results of this convergence test. Tables A.17 and A.18 present an overview of the coefficients' significance for each quarter and country. Table A.19 reports the regression results and shows that the coefficients of the bank-specific variables are in line with our previous results.

[8]To compare the characteristics of IRB banks with non-IRB banks, Table A.2 in the Internet Appendix presents descriptive statistics of all banks one quarter before adoption.

The risk profile of a bank's balance sheet can be modified either by transferring the risk to a third party, by an increase in the counterparties' credit worthiness, or by a shift in the demand for credit from high-risk customers. As total risk in the market is expected to remain at a similar level, it should be reflected in the macroeconomic variables, as changes in the counterparties' risk are linked to changes in the real economy.

Alternatively, the reduction in RWAs contributes to the banks' effort to fulfill the higher capital ratios while banks do not reduce their economic risk accordingly (e.g., Gropp et al., 2019, 2023). Potential explanations for these stylized facts include bank-level changes in the calculation approach of RWAs, different business models across banks, as well as country-level differences in the economic situation or banking regulation and supervision.[9]

The regulatory authorities allow a gradual implementation of the IRB approach. Moreover, they allow for a permanent partial use, where banks may refrain from applying the IRB approach to all portfolios (BCBS, 2004; BCBS, 2017; EBA, 2019). Banks most likely initially implement the IRB approach for portfolios where they expect the largest reduction in average risk weights per volume unit. As implementation progresses, banks may continue to reduce their risk-weights resulting in decreasing RWA densities over time.

When analyzing changes in banks' RWA density over time and across countries, regulation and supervision play a major role. Scandinavian countries may serve as an example to explain differences in their RWA density dynamics as being linked to the different levels of regulatory strength. Indeed, we find significant differences in banks' RWA density changes post switch between the Nordic countries, Norway, Finland, Sweden, and Denmark. This is in line with the different extent to which these countries have been affected by a prior banking crisis. We put forward that countries that have experienced high economic and social cost from a collapse in the banking sector have a higher willingness to impose strict minimum capital requirement regulations on banks. However, incentives to regulate further depend on whether the banking sector is robust, and if banks have the ability to build up capital through profitability. In the 1990-banking crisis, Finland, Norway, and Sweden were among the industrialized countries that experienced the most severe losses in the economy due to defaulting banks (Reinhart and Rogoff, 2008). Denmark did not experience such an impact. Thus, Denmark, being less affected, has a lower willingness to impose strict regulations on banks' minimum capital requirements, believing more in the markets' ability to self regulate. In addition, Nordic banks have high levels of exposure to mortgages on their balance sheets, and GDP and real estate price growth have a large impact on bank profitability (Martins, Serra, and Stevenson, 2019). Norway has experienced a more steady increase in GDP and real estate prices after the introduction of the IRB approach than Denmark, Sweden, and Finland. The strictest capital requirements imposed in Norway are grounded on the high profitability in the banking sector, which facilitates building up capital. Focusing on the implementation of the Third Basel Accord in Norway that has been introduced earlier than in other European countries, Juelsrud and Wold (2020) describe the implementation of this policy reform to increase capital requirements.

[9]Figure A.7 in the Internet Appendix illustrates the development of country average bank size and loan share over time. Both Panel A and B show that neither bank sizes nor their loan shares converge downward over time, indicating that there are no large changes in banks' business models and that other key bank variables do not explain the observed convergence.

Despite notable differences in economic risk levels between countries, we observe downward convergence in regulatory risk levels over time (see Figure 1).[10] In order to support the competitiveness of domestic banks, banking authorities may decide to relax regulatory requirements, having as result banks' RWA density convergence. According to the literature on regulatory leakage, the market of a strictly regulated banking sector becomes more attractive for branches of foreign banks subject to lower capital requirements (Reinhardt and Sowerbutts, 2015). An increase in foreign banks' market share can both be perceived as a threat to the banking sector, and give rise to political pressure to reduce differences in capital regulation.

3 Empirical Design

In this section, we first describe the data preparation and the sample selection procedure. Then, we describe the country grouping strategy as well as our key variables, both essential to the empirical design of our study.[11]

3.1 Data

We focus on the 80 largest listed European banks by total assets. Listed banks are required to publish financial reports quarterly, and generally provide granular information on capital, loans, losses, and profit. We employ quarterly data over a fourteen year time period to explore differences between banks, countries, and regulatory regimes. As banks have been able to obtain the IRB approach approval since 2007,[12] our data covers the period from Q1/2006 to Q4/2019, which enables us to analyze the impact of the switch to the IRB approach on banks' RWA density development.

Previous studies show that RWA densities of banks using internal models are lower than those calculated using the standardized approach. Whereas previous literature compares the levels of RWAs between banks using the IRB approach versus the standardized approach, we aim at analyzing the medium- and long-term effects of banks' switch to the IRB approach on their RWA densities. We focus solely on banks which seek and obtain approval to use an internal credit risk model during our sample period and analyse the immediate effect of the switch in a cross-sectional analysis. We furthermore identify factors that explain the development of RWA densities over time, after the switch.

Among the 80 largest listed European banks, 58 switched to the IRB approach by the end of 2019. We gather information on the IRB approach approval date which is published either in banks' annual reports or disclosure reports following the public disclosure requirements (BCBS, 2004). From banks' quarterly reports, we manually collect banks'

[10] In addition, Table A.3 in the Internet Appendix provides descriptive statistics of the RWA density per year, confirming the downward convergence. For a more detailed analysis of the convergence, please refer to Internet Appendix A.6.

[11] Table A.4 in the Internet Appendix summarizes bank- and country-specific data, as detailed in this section.

[12] Note that not all national supervisors started to approve banks' internal credit risk models in 2007. In the Internet Appendix A.3, we provide information on the year and quarter when the IRB approach adoption becomes possible for each country.

corporate loan share[13] and the share of a bank's loan portfolio, where RWAs are calculated using the IRB approach. All other quarterly bank-specific information is retrieved from the Refinitiv Datastream database. Unfortunately, the Refinitiv Datastream database contains random gaps in the time series for some entities. To improve the data quality, we replace missing values of banks' RWAs using banks' quarterly reports. Moreover, we follow Kofman and Sharpe (2003) and use imputation methods bridging short gaps to deal with missing values in banks' RWAs, net income, net loans, and loan-loss reserves data. As we calculate quarterly changes based on this information, sufficient data availability and quality are necessary to obtain unbiased results. RWA data at the quarter of the switch and for the subsequent four quarters is missing for six banks which switched at the beginning of the sample period. We eliminate these six banks, as the corresponding quarterly reports are no longer available on banks' websites, and imputation techniques are not applicable or would bias the cross-sectional analysis. Our final data set includes 52 listed banks[14] headquartered in 14 European countries.[15]

We measure country risk based on the 5-year sovereign credit-default swap (CDS) spreads taken from the Refinitiv Datastream database. In addition to cross-country differences in risk, we take into account the economic outlooks as well as the regulatory stringency and the supervisory power for each country. Country-specific macroeconomic data originates from the International Monetary Fund and the World Bank. Information on regulatory stringency and supervisors' disciplinary power across countries is based on the World Bank's Bank Regulation and Supervision Survey.[16] The capital regulatory index evaluates the countries' regulatory capital rules and their capacity to result in a reliable regulatory capital base. The index ranges from 0 to 10 where higher values indicate greater regulatory stringency. The supervisory power index assesses the supervisors' authority to enforce applicable regulations and to conduct effective bank resolution activities. The index ranges from 0 to 14 and higher values indicate greater supervisory power.

3.2 Country grouping

To structure the countries in our cross-sectional data set and check if there are systematic differences in banks' RWA density development after the switch, we group the countries based on sovereign risk as well as regulatory and supervisory strictness. Table 2 summarizes the country grouping based on national levels of banking regulation and supervision, and according to sovereign CDS spreads, highlighting the pecking order how countries

[13]Unfortunately, we only have this information available for a subset of banks, precisely for 37 out of 52 banks and 59.6 % of observations of our sample.

[14]Table A.5 in the Internet Appendix provides a list of all banks including their IRB adoption date.

[15]Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. Table A.6 in the Internet Appendix presents an overview of our data set across countries.

[16]Our data is based on the 2007, 2011, and 2019 surveys. We summarize the survey questions used in both indices as suggested by Barth, Caprio, and Levine (2013) in the Internet Appendix A.5. Following Barth, Caprio, and Levine (2004) and Anginer, Demirgüç-Kunt, and Zhu (2014), we assume that regulations are persistent over time and rely on a country's index value until new information is available. Index values of all countries in our data set based on the 2007 and 2011 survey are retrieved from Barth et al. (2013). To track the more recent changes, we calculate the index values based on the latest survey published in 2019 for the years 2018 and 2019.

have been classified. The classification of high-risk countries is in line with Beltratti and Paladino (2016), the classification based on supervisory power and regulatory stringency further specifies specific countries.[17]

Table 2: Overview of the country grouping.

		Sovereign Credit Risk		Supervisory Power		Regulatory Stringency	
Country	**Classification**	**Average**	**Rank**	**Average**	**Rank**	**Average**	**Rank**
Ireland	high-risk	157.15	**1**	8.86	10	5.97	7
Italy	high-risk	131.41	**2**	10.43	5	5.07	4
Spain	high-risk	108.49	**3**	10.68	4	8.14	14
Switzerland	strict supervision	33.75	8	12.71	**1**	7.00	10
Austria	strict supervision	32.06	9	11.21	**2**	5.14	5
Sweden	less strict regulation	22.56	12	8.86	10	3.93	**1**
Denmark	less strict regulation	28.25	10	10.07	6	4.50	**2**
Belgium	remaining countries	51.26	4	10.93	3	6.04	8
Finland	remaining countries	26.29	11	7.50	14	4.93	3
France	remaining countries	35.11	6	9.43	9	7.64	13
Germany	remaining countries	18.09	13	9.57	8	7.21	11
Netherlands	remaining countries	34.45	7	10.02	7	6.79	9
Norway	remaining countries	17.86	14	8.50	13	7.50	12
UK	remaining countries	38.72	5	8.64	12	5.14	5

This table shows mean values of the indices describing regulatory stringency and supervisory power, and the sovereign credit default swap (CDS) spreads per country as well as the country ranking for the three categories. The country grouping as used in the cross-sectional analysis is summarized in the second column. In the panel analysis, we use the variables described in Table A.8 to track the development of regulatory and supervisory strictness and country risk over time. CDS spreads are retrieved from Refinitiv Datastream and the two indices are calculated from data provided by the World Bank's Bank Regulation and Supervision Surveys as suggested by Barth et al. (2013). Internet Appendix A.5 provides an overview of both indices.

First, to distinguish the countries' risk level, we rely on sovereign CDS spreads. CDS spreads are especially suitable for our study, as they provide information on country-specific credit risk on a daily basis (e.g., Fontana and Scheicher, 2016). We classify a country as a high-risk country if its average CDS spread across the sample period is larger than 100 basis points. Hence, Ireland, Italy, and Spain are categorized as high-risk countries.[18] Similarly, Beltratti and Paladino (2016) classify these three countries among the European peripheral ones[19], supporting our classification of high-risk countries.

Second, we take into account differences in the countries' regulation and supervision based on the two indices suggested by Barth et al. (2013). On the one hand, strict supervision may prevent moral hazard behavior and force banks to refrain from further

[17]To highlight the importance of the country grouping for our analysis, we discuss this in a dedicated robustness test presented in Table A.20 in the Internet Appendix. The changes in R^2 show that the classification is a pivotal part of explaining RWA density changes.

[18]In Table 2, we illustrate the country grouping with reference to the classification of high-risk countries. Figure A.9 in the Internet Appendix presents the development over time of sovereign CDS spreads across the countries in our data set. Unsurprisingly, a classification based on sovereign credit ratings, which summarizes available macroeconomic and market-based information, results in the same categorization of high-risk countries (e.g., Hilscher and Nosbusch, 2010).

[19]Beltratti and Paladino (2016) analyze the effect of the Second Basel Accord on banks' RWA density during the 2008 financial crisis and the sovereign debt crisis. The authors classify Cyprus, Greece, Ireland, Italy, Portugal, and Spain as the peripheral countries and indicate that they are associated with high country risk.

reducing their RWA densities. According to Barth et al. (2013), Switzerland and Austria score the highest supervisory power index values, on average. On the other hand, banks in countries with less tight regulation may be able to reduce their RWA densities below the appropriate level. Especially in Europe, where the authorities allow for a gradual roll-out of the IRB approach, banks have incentives to adjust their asset composition towards more risky assets (Dautović, 2020). Again, referring to Barth et al. (2013), regulatory stringency in Sweden and Denmark is the lowest on average between 2007 and 2019. Facing less strict regulation, especially banks in those countries are able to exploit moral hazard incentives. The fact that the 2018 regulation change introducing higher capital requirements in Sweden is specifically targeting banks with IRB approach approval, corroborates this assertion (Finansinspektionen Sweden, 2018).

As illustrated in Figure A.1 in the Internet Appendix, the impact of the IRB approach adoption on the evolution of banks' RWA densities shows distinguishing patterns across country groups classified with respect to sovereign risk, as well as regulatory and supervisory strictness. Table 2 additionally includes the country ranking for each of the three categories. Specifically, the concurrence of different levels of regulatory stringency and supervisory power is expected to influence banks' strategies. As an example, banks in countries with strict regulation may be able to exploit leeway due to low supervisory power. Moreover, regulatory authorities may refrain from strict supervision in countries with high country risk. In the panel analysis, we take into account dynamics with respect to countries' regulatory stringency, supervisory power, and sovereign credit risk.

3.3 Variables and descriptive statistics

Our empirical study comprises both cross-sectional and panel analyses, relying on two distinct data sets. To create the cross-sectional data set, we focus on the differences between individual banks and define our variables relative to the switching date or use averages across the sample period with one observation per bank. Adding the time dimension, the panel data set additionally tracks the development of the variables for the time period between Q1/2007 and Q4/2019. In the following, we present the key variables in detail and explain their choice in function of the analysis.[20]

Cross-section

In the cross-sectional analysis, we define both short- and long-term RWA density changes relative to the quarter of the IRB approach approval. First, to analyze the RWA density reduction[21] right after the switch, let us define $\Delta RWAD^{s}_{i,j}$ for bank i in country j as the percent change in RWA density at the end of the quarter of the switch s compared to the end of the quarter before approval. To additionally model the long-term development after the switch, we calculate the average of the quarterly changes in RWA density across r quarters after the switch ($\varnothing\Delta RWAD^{s+r}_{i,j}$). However, as several banks switch later during

[20]Tables A.7 and A.8 in the Internet Appendix provide the definitions of all variables included in both analyses. Descriptive statistics of all variables are provided in Tables A.9 and A.10 in the Internet Appendix. Non-binary bank-specific panel variables are winsorized at the 1% and 99% levels. Tables A.11, A.12 and A.13 in the Internet Appendix present the correlation matrices.

[21]Following previous literature, we expect a reduction in RWA densities for the majority of banks (see Section 1).

our sample period, the number of available banks and therefore the number of observations in the cross-section decreases.[22]

Most importantly, we include indicator variables to control for the country grouping explained in Section 3.2. The indicators $HIGH\_RISK_j$, $LAX\_REGULATION_j$, and $STRICT\_SUPERVISION_j$ track the differences in RWA density changes across country groups.[23] To illustrate the importance of disentangling between short- and long-term RWA density reductions, Figure 2 presents the development of the mean RWA density relative to the quarter of IRB approval $s = 0$.[24]

For the short-term dynamics, we control for the distance of RWA densities relative to the countries' minimum risk-weighted assets density at the quarter before the bank obtains the approval to use the IRB approach ($REL\_MIN_{i,j}^{s-1}$). Larger values indicate that a bank has more potential to reduce its RWA density. For the long-term development, we instead include $\varnothing RWAD_{i,j}$ to take into account the impact of a trend in total assets influencing the banks' average RWA density development across the sample period. Similarly, the variables equity to total assets and bank size are either defined relative to the quarter of the switch ($EQUITY_{i,j}^{s-1}$ and $SIZE_{i,j}^{s-1}$) or as the average across the sample period ($\varnothing EQUITY_{i,j}$ and $\varnothing SIZE_{i,j}$. Whereas the former approach is comparable to the M&A literature (e.g., Mehran and Thakor, 2011), the latter ensures that the variable reflects the whole sample period (e.g., Goddard, Molyneux, and Wilson, 2004). All other explanatory variables in the cross-sectional analysis are the same for both versions of the dependent variable.

Moreover, we address possible confounding factors which are expected to impact the RWA density development. Particularly, banks gradually implement the IRB approach across portfolios after they obtain approval (BCBS, 2004; BCBS, 2017). The gradual roll-out process may have both a short- as well as a long-term effect on the evolution of RWA densities since banks are expected to start calculating the IRB approach for portfolios with the largest expected RWA density reduction (BCBS, 2004; Schlam and Woyand, 2023). In the analysis of the effect of IRB approach implementation on banks' RWA densities, we use the share of banks' loan portfolio where RWAs are calculated based on the IRB approach at the quarter of the switch. The variable $IRB\_COVERAGE_{i,j}^{s}$ describes the initial coverage of the IRB approach at the first quarter where a bank uses an internal model.

Besides, banks' net income to RWAs $RETURN\_ON\_RWA_{i,j}^{s-1}$ or the share of loan-loss reserves at the quarter before the switch $LLR_{i,j}^{s-1}$ may further affect the RWA density reduction upon approval (EBA, 2015b). We furthermore introduce three indicator vari-

[22]As illustrated in Figure 3, the majority of banks chooses to apply for IRB approach approval before the end of 2009. Thus, we can calculate the average RWA density change across 40 quarters for 41 banks. To test if our results are systematically influenced by late switchers, we estimate the cross-sectional model based on the subsample of 41 banks that switch early. The results of this robustness test, presented in Table A.21 in the Internet Appendix, confirm our conclusions as detailed in Section 5.1 and we find that the coefficient of the variable $HIGH\_RISK_j$ is already significant in column (4) when estimating the effect on the average RWA density change eight years after switching.

[23]We relax this assumption and use categorical variables of supervisory power and regulatory stringency and present the results in Table A.22 in the Internet Appendix. In addition, we test an alternative country grouping (see Table A.23). The results show that our findings hold true for other classifications.

[24]Note that differences across country groups are illustrated in Figures A.1 and A.10 in the Internet Appendix.

ables to describe bank-specific characteristics in our sample ($PRE\_CRISIS_{i,j}$, $EURO_{i,j}$, and $G\_SIB_{i,j}$). As the majority of banks obtain approval shortly after switching becomes possible in their country and most banks switch before the crisis, the timing may influence the banks' options to reduce their RWA densities. Moreover, we control for effects specific to the euro area.[25] As an example, euro banks are part of the European Banking Union and with the introduction of the so called Single Supervisory Mechanism in 2014, the European Central Bank (ECB) becomes their central supervisor (ECB, 2018). Finally, taking into account the classification as Global Systemically Important Bank (G-SIB) controls for differences due to tighter supervision of global systemic banks and addresses the effect of regulatory changes specific to G-SIBs.

On the country level, we also create variables based on averages across the sample period ($\varnothing DOMESTIC\_CREDIT_j$ and $\varnothing\Delta GDP_j$). Hereby, we take into account that capital regulation may influence bank lending in a way that banks reduce credit supply to meet minimum capital requirements (e.g., Hyun and Rhee, 2011; Behn et al., 2016), and consider overall macroeconomic dynamics.

Panel analysis

In the panel analysis, we use the quarterly change in RWA densities ($\Delta RWAD_{i,j,t}$) as dependent variable, exploring the development over time and across banks. In contrast to the two versions of banks' RWA density change used in the cross-sectional model, this variable does not relate to the quarter of approval but tracks the RWA density changes on a quarterly basis between Q1/2007 and Q4/2019.[26] As described by Lindquist (2004), we observe a seasonal variation of RWA density changes. This seasonality is a result of accumulation of profit before annual distribution of dividends to shareholders. Interestingly, both mean and median of banks' change in RWA density for banks in countries with less strict regulation and in high-risk countries are negative and the lowest across groups, suggesting that these banks substantially reduce their RWA densities.[27]

The variation in RWA density changes may be attributed to particular events. Negative changes, especially during the first three years of our observation period, relate to banks' IRB approach approval. Positive changes at the end of 2013 can be attributed to the implementation of the Capital Requirements Directive IV, introducing higher capital requirements in the euro countries.[28] The higher positive changes in the countries with strict supervision can be explained by the introduction of higher capital requirements for the two large Swiss banks to be implemented until 2013. Moreover, the targeted review of internal models (TRIM) plays an important role for euro countries. Launched by the ECB at the beginning of 2016, TRIM assessed whether banks' internal models are compliant with regulatory requirements and investigated the reliability and comparability of their results. According to the ECB, the TRIM investigations resulted in an increase in RWA and banks are required to maintain and further develop their internal models (ECB,

[25]Euro countries include Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands, and Spain.

[26]Figure A.8 in the Internet Appendix illustrates the development over time across country groups (Panel A to D).

[27]Table A.14 in the Internet Appendix provides summary statistics of the variable $\Delta RWAD_{i,j,t}$ across country groups.

[28]Similarly, the introduction of higher capital requirements for Swedish banks at the end of 2018 explains the spike in Panel A of Figure A.8 in the Internet Appendix.

2021). We provide an overview of relevant events in the European banking system during our sample period in the Internet Appendix A.3.

Again referring to Figure 1 and Table 1, they provide interesting insights into the development of the countries' quarterly mean of banks' RWA densities. Focusing on the high-risk countries, banks initially have high RWA densities and start using the IRB approach later than several banks in the other countries. As shown in Table 1, the average RWA density of these banks is substantially lower ten years after the switch. Similarly, banks in the two countries with less strict regulation have been able to reduce their RWA densities over time. In contrast, the RWA densities of Norwegian banks, representing a special case among the remaining countries as discussed in Section 2, slightly decreased but remained on a very high level (see Figure 1). Among the countries with strict supervision, average RWA densities of Austrian banks have already been on a high level at the time of the switch and remained so. Even though the RWA densities of Austrian banks decrease at times, we observe a notable increase, which is due to a response to the additional capital requirements introduced by the Capital Requirements Directive IV, which was implemented in the EU until the end of 2013 (EU, 2013). In Switzerland, RWA densities were the lowest in Europe until 2012 but capital of Swiss banks almost doubled within ten years, as the responsible authorities introduced higher capital requirements for the two largest Swiss banks to be implemented by 2013 (Swiss Bankers Association, 2009).[29]

Similar to the cross-sectional analysis, the key explanatory variables relate to the countries' regulatory and supervisory strictness, as well as economic conditions. The indicator variable $LAX\_REGULATION_{j,t}$ is equal to 1 if the country is classified as country with less stringent regulation. The indicator $STRICT\_SUPERVISION_{j,t}$ is equal to 1 if the country is classified as country with strict supervision.[30] Moreover, we include $CDS\_SOVEREIGN_{j,t}$, calculated as the natural logarithm of countries' sovereign CDS spreads.[31] As described in Section 3.2, sovereign risk mirrors the countries' risk level (e.g., Fontana and Scheicher, 2016). Corresponding to the country grouping in the cross-sectional analysis, we expect differences in RWA density development to depend on country risk. National authorities may relax certain aspects of banking regulation and/or supervision as a response to high sovereign risk, leading to the possibility to further reduce their RWA densities. As individual bank risk may differ from country risk, we alternatively calculate the variable $CDS\_BANK_{i,j,t}$ as the natural logarithm of banks' CDS spreads for all banks where this data is available.

The two indicator variables $G\_SIB_{i,j,t}$ and $IRB_{i,j,t}$ are important to consider if a bank is classified as G-SIB, and if a bank uses the IRB approach.[32] Similar to the cross-

[29] We summarize the timeline of relevant events in the European banking sector in the Internet Appendix A.3.

[30] Alternatively, we use the two categorical variables $REGULATION\_INDEX_{j,t}$ and $SUPERVISION\_INDEX_{j,t}$, representing the two indices as detailed in Table A.8, to test the robustness of our findings. The results presented in Table A.27 in the Internet Appendix confirm results discussed in Section 5.2.

[31] We use the natural logarithm to deal with outliers, as illustrated by Figure A.9. Results are robust to using the absolute value of countries' sovereign CDS spreads instead of the natural logarithm.

[32] Banks may either seek approval to use the advanced IRB approach, which permits the estimation of the probability of default, the exposure at default, and the resulting loss, or to use the foundation IRB approach, which only allows to estimate the probability of default based on internal models. As the risk weight depends on the probability of default for both the advanced and the foundation IRB approach, we do not distinguish between the two (Behn et al., 2016; Dautović, 2020). Due to the gradual

section analysis, quantifying the gradual implementation across portfolios over time, the variable $IRB\_COVERAGE_{i,j,t}$ tests whether RWA density reduction depends on the IRB approach coverage.

Changes in relevant bank fundamentals are expected to influence RWA density development. Banks which increase their net loans are expected to increase their RWA densities. To control for the banks' asset composition, we use either the change of banks' net loans or of their corporate loan share ($\Delta LOANS_{i,j,t}$ or $\Delta CORPORATE\_LOANS_{i,j,t}$).[33] Similarly, banks which increase their share of loan-loss reserves ($\Delta LLR_{i,j,t}$) are expected to tie up more capital. Furthermore, $\Delta RETURN\_ON\_RWA_{i,j,t}$ and $\Delta EQUITY_{i,j,t}$ take into account that authorities may relax requirements for low profitability banks as they cannot cope with high minimum capital requirements, and control for the banks' available equity capital, respectively. Finally, facing comparatively high capital requirements, especially small banks may aim to lower their RWA densities to reduce costs. Thus, we include the variable $SIZE_{i,j,t}$.

As discussed for the cross-section, we take into account the countries' level of bank credit supply ($DOMESTIC\_CREDIT_{j,t}$) and the countries' real GDP ($\Delta GDP_{j,t}$). Finally, it is important to account for the seasonality across quarters. Following Lindquist (2004), we include quarter indicators and expect a systematic seasonal effect with an increase in RWA densities within each year.

4 Methodology

We address the question of why the RWA density reduction differs across countries and over time, based on two different empirical approaches. Similarly to Beck and Levine (2004), we begin with the cross-section and subsequently estimate a panel data model to analyze the development over time. These two steps are especially suitable for the purpose of our study because they complement each other. First, the cross-sectional analysis sheds light on factors that explain the RWA density change directly at the quarter of the switch as well as the subsequent RWA density development relative to the quarter of the switch. Second, in the frame of the panel model, we identify the bank-specific and macroeconomic factors to study quarter-to-quarter changes in RWA densities.

The empirical design of our cross-sectional analysis is comparable to the empirical model developed by Mehran and Thakor (2011). The authors analyze bank capital structure in the context of bank mergers and define most variables used in their cross-sectional analysis relative to the acquisition announcement date. Similarly, our employed variables are observed relative to the approval date of the IRB approach. We aim at analysing the short-term reduction in RWA densities upon IRB approval observed at the quarter of the switch as well as in the subsequent quarters. Equation (1) formalizes the cross-sectional model:

$$\Delta RWAD_{i,j} \quad = \quad \alpha_i + \beta \cdot GROUPING'_j + \delta \cdot CONTROLS'_{i,j} + \varepsilon_i, \tag{1}$$

implementation of internal models, almost all banks in our data set use the advanced IRB approach in 2019 with the result that higher flexibility seems to coincide with convergence.

[33] The corporate loan share is available for a subset of 37 banks out of 52 banks and 59.6 % of observations of our sample.

where, for bank i in country j, $\Delta RWAD_{i,j}$ refers to the dependent variable estimated for the two versions, as defined in Section 3.3, α_i represents bank-specific effects, and ε_i denotes the error term. $GROUPING_j$ describes a vector of indicator variables which are defined according to the country grouping as described in Section 3.2 and detailed in Table 2. The vector $CONTROLS_{i,j}$ contains all other relevant bank-specific and macroeconomic control variables as detailed in Section 3.3.

In the panel analysis, we aim to understand whether the evolution of RWA densities over time accomplishes the purpose of the IRB approach regulations. We expect differences in countries' economic situation to be reflected in differences in RWA densities, as most banks' balance sheets contain primarily home country assets. We take into account both bank-specific information, as well as differences in macroeconomic conditions, financial regulatory frames, and supervision regimes across countries. After testing the relevant variables for stationarity, we use a fixed-effects estimation procedure based on a heteroscedasticity robust covariance matrix. Equation (2) illustrates the formal design of our regression model:

$$\Delta RWAD_{i,j,t} \quad = \quad \eta_i + \vartheta \cdot GROUPING'_{j,t-1} + \omega \cdot CONTROLS'_{i,j,t-4} + \zeta \cdot q'_t + \tau_t + \xi_{i,j,t}. \qquad (2)$$

For bank i in country j and quarter t, $\Delta RWAD_{i,j,t}$ represents the dependent variable. $GROUPING_{j,t-1}$ refers to a vector containing the main explanatory variables, and the vector $CONTROLS_{i,j,t-4}$ includes the remaining control variables, as detailed in Section 3.3.[34] Moreover, we include a vector of quarter indicators (q_t) to adjust for the RWA density seasonality and quarter-fixed effects (τ_t) to capture effects specific to a quarter during the observation period.[35] η_i represents unobserved time-invariant individual bank-specific effects and $\xi_{i,j,t}$ denotes the error term. To identify the different effects across country groups, we introduce interaction terms between the grouping variables and the IRB variable ($GROUPING_{j,t-1} \times IRB_{i,j,t-1}$).

5 Empirical results and interpretation

5.1 Cross-sectional analysis

In Tables 3 and 4, we show estimation results of Equation (1) for changes in RWA density at the time of the switch and in the subsequent quarters, respectively, for the list of variables defined in Table A.7.

As shown in Table 3, the coefficients of $LAX\_REGULATION_j$ are negative and statistically significant, confirming that banks in countries with less strict regulation are able to reduce their RWA densities right after the switch. In contrast, the coefficients of the variable $STRICT\_SUPERVISION_j$ are positive and statistically significant, suggesting that banks in countries with strict supervision show a short-term increase in RWA densities. On average, as illustrated in Figure A.10, RWA densities of banks in all country groups decrease, implying that RWA densities of banks in countries with strict supervision

[34] As $\Delta RWAD_{i,j,t}$ is calculated as the change in quarter t compared to the previous quarter, we use lagged explanatory variables. As the effect of the bank-specific and macroeconomic variables is not expected to directly influence banks' RWA densities, we use the four-quarter lagged variables.

[35] For an overview of events in the European banking system during our sample period which are relevant in specific quarters, see Internet Appendix A.3.

decrease relatively less than other banks in the sample. Similarly, the coefficients of the variable $HIGH\_RISK_j$ are positive and in columns (1) to (4) statistically significant, suggesting that RWA densities of banks in high-risk countries increase or decrease less than other banks upon IRB approach approval. This seems plausible, as regulators originally intended internal credit risk models to be more risk-sensitive than the standardized approach, requiring regulatory capital according to banks' actual credit risk.

Moreover, the $EURO_{i,j}$ coefficient is statistically significant and of negative sign, indicating that banks headquartered in euro countries have been able to reduce their RWA densities more than other banks when switching to the IRB approach. This effect is mainly driven by the Dutch, German and Finish banks in our sample. Our results imply that supervisors in euro countries allowed more flexibility in RWA density calculations.

To analyze the role of regulatory strictness in greater detail, we additionally introduce the variable $G\_SIB_{i,j}$ and present the results in column (2). Starting in 2012, the BCBS introduced the G-SIB framework where banks above a particular threshold value are identified as global systemic banks and are required to meet higher regulatory requirement. However, most banks in our sample adopted the IRB approach before 2009 with the result that the classification as G-SIB does not influence the effect at the quarter of the switch.

We additionally introduce the variable $IRB\_COVERAGE^s_{i,j}$ to test if the gradual roll-out process of the IRB approach influences our findings and present the results in column (3). Typically, banks start implementing the IRB approach for portfolios where they expect the largest RWA density reductions (Dautović, 2020). If the reduction was mainly influenced by the gradual implementation process, banks with a high initial IRB approach coverage at the quarter of the switch would have larger RWA density reductions. Yet, the coefficient of the variable $IRB\_COVERAGE^s_{i,j}$ is not statistically significant.[36]

Bank's profitability before the switch may further influence capital adjustments upon IRB approach approval. Thus, in column (4), we test for the impact of the return to RWAs at the quarter before the switch ($RETURN\_ON\_RWA^{s-1}_{i,j}$). We find that the RWA density changes at the quarter of the switch do not depend on bank profitability. Hence, in line with the regulatory intention, return considerations do not influence the RWA density change (BCBS, 2001).

Similarly, we employ the variable $LLR^{s-1}_{i,j}$ to account for the banks' credit risk exposure at the quarter before the switch. The results presented in column (5) corroborate the grouping of high-risk countries. The positive and significant coefficient of the variable $LLR^{s-1}_{i,j}$ confirms our expectation that banks with a high share of loan-loss reserves before the switch reduce their RWA densities less than other banks. As larger reserves for loan-losses indicate higher credit risk, this finding confirms that, due to the higher risk-sensitivity of the IRB approach, banks with high risks are associated with increasing RWA densities after switching. Results are presented in Table 3 confirm findings by Mariathasan and Merrouche (2014) and provide initial evidence that IRB approach adoption increases

[36]Similarly, we take into account the influence of the IRB approach implementation process when analyzing the long-term development after the switch (see Table 4). In Table A.24 in the Internet Appendix, we replicate results when including the additional variable $\varnothing HIGH\_IRB\_CVG_{i,j}$, which indicates if a bank's average IRB approach coverage is larger than the third quartile, corresponding to 81.7%. Results show that the implementation process only influences the average RWA density reductions up until about two years after the switch. In the long run, the gradual implementation process does not explain why banks further reduce their RWA densities.

the spread between banks' RWA densities at the time of the switch, especially as banks in high-risk countries with high initial values further increase their RWA densities.

Table 3: Cross-sectional analysis: effect at the quarter of the switch.

	Dependent variable: $\Delta RWAD^{s}_{i,j}$				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
$G\_SIB_{i,j}$		0.179 (6.351)			
$IRB\_COVERAGE^{s}_{i,j}$			−2.925 (5.663)		
$RETURN\_ON\_RWA^{s-1}_{i,j}$				−1.118 (4.240)	
$LLR^{s-1}_{i,j}$					1.406* (0.757)
$LAX\_REGULATION_{j}$	−12.129* (7.060)	−11.983 (9.225)	−11.816* (7.064)	−12.222* (7.248)	−13.252* (7.902)
$STRICT\_SUPERVISION_{j}$	9.625* (5.114)	9.670* (5.474)	9.571* (5.214)	9.528* (5.260)	7.656 (5.550)
$HIGH\_RISK_{j}$	8.801* (4.913)	8.855* (5.334)	8.521* (4.745)	8.866* (4.971)	6.428 (6.053)
$PRE\_CRISIS_{i,j}$	4.240 (4.364)	4.258 (4.427)	4.281 (4.366)	4.467 (4.494)	4.652 (4.445)
$EURO_{i,j}$	−8.705*** (3.110)	−8.678** (3.529)	−8.546*** (3.141)	−9.042*** (3.208)	−8.432** (3.554)
$REL\_MIN^{s-1}_{i,j}$	0.246 (0.171)	0.246 (0.177)	0.248 (0.173)	0.237 (0.174)	0.174 (0.197)
$EQUITY^{s-1}_{i,j}$	−0.402 (1.165)	−0.406 (1.222)	−0.465 (1.176)	−0.285 (1.244)	−0.348 (1.180)
$SIZE^{s-1}_{i,j}$	0.509 (0.990)	0.485 (1.211)	0.514 (0.991)	0.524 (1.022)	0.181 (1.047)
$\varnothing DOMESTIC\_CREDIT_{j}$	−0.101 (0.070)	−0.102 (0.089)	−0.100 (0.069)	−0.103 (0.071)	−0.097 (0.076)
$\varnothing \Delta GDP_{j}$	−1.461 (5.575)	−1.424 (5.562)	−1.754 (5.580)	−0.754 (5.996)	0.052 (6.511)
Constant	−6.701 (11.595)	−6.388 (15.632)	−4.890 (11.852)	−6.814 (11.945)	−2.862 (14.121)
Observations	52	52	52	52	48
R^2	0.355	0.355	0.360	0.357	0.350
Adjusted R^2	0.198	0.178	0.184	0.180	0.151
Residual Std. Error	9.784 (df = 41)	9.905 (df = 40)	9.871 (df = 40)	9.893 (df = 40)	9.806 (df = 36)
F Statistic	2.259** (df = 10; 41)	2.003* (df = 11; 40)	2.042** (df = 11; 40)	2.017* (df = 11; 40)	1.761* (df = 11; 36)

This table reports regression results of the cross-sectional analysis with robust standard errors in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Key variables: $\Delta RWAD^{s}_{i,j}$ is calculated as the change in bank i's risk-weighted assets to total assets from the quarter before the switch to the quarter of the switch s in percent. $LAX\_REGULATION_{j}$, $STRICT\_SUPERVISION_{j}$, and $HIGH\_RISK_{j}$ are indicator variables equal to 1 if country j is classified as country with less strict regulation, strict supervision, and high country risk, respectively, and 0 otherwise. Comprehensive variable descriptions of all other variables are provided in Table A.7 in the Internet Appendix.

We further analyze the long-term development after the switch to the IRB approach by employing the variable $\varnothing \Delta RWAD_{i,j}^{s+r}$ as the dependent variable. Table 4 reports results for $r = \{8, 16, 24, 32, 40\}$ quarters, corresponding to the average of the quarterly changes across 2, 4, 6, 8, and 10 years after the switch.[37] The explanatory power, which ranges from 0.272 to 0.413, is fairly high, confirming previous findings of Mehran and Thakor (2011).

The coefficients of the grouping variables suggest two interesting conclusions. First, the levels of regulatory and supervisory strictness play a significant role. The coefficients of the variable $LAX\_REGULATION_j$ ($STRICT\_SUPERVISION_j$) in columns (2) to (5) are all negative (positive). Even though the magnitudes are lower than in Table 3, they confirm the direction of the effect at the quarter of the switch across the sample period. Second, the coefficient of the variable $HIGH\_RISK_j$ is negative and statistically significant when estimating the effect on the average RWA density change ten years after the switch, as shown in column (5). Thus, if high sovereign risk implies that RWA densities remain on a high level in the short term, the effect is reverted in the long term. Even though the introduction of internal credit risk models has initially resulted in high RWA densities mapping high risk, this effect diminishes over time. Instead, banks in high-risk countries have been able to substantially reduce their RWA densities, which fosters convergence across countries.[38]

Moreover, coefficients of the variable $PRE\_CRISIS_{i,j}$ in columns (1), and (2) are positive and significant. This finding suggests that early switchers are associated with increasing RWA densities and did not necessarily benefit in terms of RWA density reductions in the long term. Potentially, after the 2008 financial crisis, banks only seek IRB approach approval if they expect large RWA density reductions.

To test the robustness of the country grouping, we include individual country indicators instead of country grouping indicators. To estimate the model, we have to exclude the country-specific variables. Table 5 provides the results of the cross-sectional model with country indicators, again corresponding to the average changes across r quarters after the switch. The findings allow a valuable insight into country differences and corroborate the grouping discussed in Section 3.2. Most coefficients of the country indicators in column (5) are negative and significant, including the high-risk countries Ireland and Italy. The fact that their coefficients are among the largest coefficients by absolute value in column (5) confirms our conclusion that banks in these countries have been able to further reduce their RWA densities in the long-term after the switch. Documenting an even more pronounced reduction, the coefficients which describe Denmark and Sweden, representing the two countries with less strict regulation, equal even larger absolute values. Overall, the coefficients representing these countries are negative and most of them are statistically significant. As an example, the coefficients of the country indicators of Belgium and Finland are rather large as well. Most other countries only have one or two significant coefficients, so banks in those countries do not seem to be able to reduce their

[37] We replicate the analysis for alternative dependent variables corresponding to 1, 3, 5, 7, and 9 years after the switch and report the results in Table A.25 in the Internet Appendix.

[38] To test the robustness of the country grouping, we modify the classification of countries based on the ranking detailed in Table 2. As an example, we report results when additionally defining Finland as country with less strict regulation and Belgium as country with strict supervision in Table A.26 in the Internet Appendix. The robustness checks based on the broader country grouping confirm our conclusions.

Table 4: Cross-sectional analysis: long-term development after the switch.

	Dependent variable: $\varnothing\Delta RWAD_{i,j}^{s+r}$				
	$r = 8$	$r = 16$	$r = 24$	$r = 32$	$r = 40$
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
$LAX\_REGULATION_j$	−0.253	−1.587**	−1.988***	−2.231***	−2.151***
	(1.491)	(0.733)	(0.512)	(0.599)	(0.481)
$STRICT\_SUPERVISION_j$	2.595**	0.789	0.988**	0.770	0.487
	(1.141)	(0.747)	(0.434)	(0.475)	(0.377)
$HIGH\_RISK_j$	0.059	−0.394	−0.280	−0.703	−0.812*
	(1.178)	(0.577)	(0.618)	(0.562)	(0.420)
$\varnothing RWAD_{i,j}$	0.053	0.003	−0.014	−0.010	−0.018
	(0.041)	(0.025)	(0.026)	(0.023)	(0.019)
$PRE\_CRISIS_{i,j}$	1.552*	0.994**	0.586	0.994	0.217
	(0.921)	(0.422)	(0.449)	(0.611)	(0.356)
$EURO_{i,j}$	−0.336	−0.262	−0.596	−0.159	0.021
	(0.703)	(0.386)	(0.436)	(0.421)	(0.315)
$\varnothing EQUITY_{i,j}$	−0.296	−0.026	0.105	−0.011	0.007
	(0.242)	(0.126)	(0.146)	(0.135)	(0.103)
$\varnothing SIZE_{i,j}$	0.284	−0.020	0.027	−0.014	−0.088
	(0.286)	(0.150)	(0.133)	(0.121)	(0.110)
$\varnothing DOMESTIC\_CREDIT_j$	−0.022	−0.004	0.005	0.010*	0.012***
	(0.014)	(0.007)	(0.006)	(0.005)	(0.004)
$\varnothing\Delta GDP_j$	0.744	−0.294	−0.355	0.673	0.573**
	(0.777)	(0.410)	(0.480)	(0.476)	(0.278)
Constant	−4.601	−0.571	−1.338	−1.577	0.029
	(4.502)	(2.652)	(2.345)	(1.798)	(1.699)
Observations	50	49	48	46	41
R^2	0.424	0.440	0.427	0.482	0.560
Adjusted R^2	0.277	0.292	0.272	0.334	0.413
Residual Std. Error	1.895 (df = 39)	0.965 (df = 38)	0.970 (df = 37)	0.902 (df = 35)	0.677 (df = 30)
F Statistic	2.874*** (df = 10; 39)	2.981*** (df = 10; 38)	2.752** (df = 10; 37)	3.258*** (df = 10; 35)	3.811*** (df = 10; 30)

This table reports regression results of the cross-sectional analysis with robust standard errors in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Key variables: $\varnothing\Delta RWAD_{i,j}^{s+r}$ is calculated as the average change in bank i's risk-weighted assets to total assets across r quarters after the quarter of switch s in percent. $LAX\_REGULATION_j$, $STRICT\_SUPERVISION_j$, and $HIGH\_RISK_j$ are indicator variables equal to 1 if country j is classified as country with less strict regulation, strict supervision, and high country risk, respectively, and 0 otherwise. Comprehensive variable descriptions of all other variables are provided in Table A.7 in the Internet Appendix.

RWA densities to the same extent. In contrast, the positive and significant coefficients of the country indicators of Austria and Switzerland demonstrate the effect of strict supervision. Especially, the tightening of regulation for the large banks in Switzerland (see Internet Appendix A.3) in combination with overall strict supervision forced banks to substantially increase their RWA densities. Unsurprisingly, the remaining results are very similar to the findings presented in Table 4.

5.2 Panel analysis

We estimate Equation (2) and introduce interaction terms between the grouping and the IRB variable to shed light on factors influencing the development of RWA density quarter-to-quarter changes. Table 6 reports regression results based on the baseline model in column (1), and the results with interaction terms in columns (2) to (4).[39]

The results reported in Table 6 extend our findings from the cross-sectional analysis of long-term RWA density adjustments. The negative and significant coefficient of the variable $LAX\_REGULATION_{j,t-1}$ shown in columns (1) to (4) confirms the overall downward trend of RWA densities in countries with less strict regulation over time. With respect to the variable $STRICT\_SUPERVISION_{j,t-1}$, the coefficient is positive, as shown in columns (1), (2), and (4), suggesting that RWA densities in countries with strict supervision increase in recent years. Interestingly, the coefficient in column (3) is negative and significant. Even if there is an initial reduction in RWA density in countries with strict supervision, there is a large and highly significant countereffect after a bank has implemented the IRB approach. Similar, there is a positive and significant coefficient of the interaction term $LAX\_REGULATION_{j,t-1} \times IRB_{i,j,t-1}$. Yet, in this case, the coefficient is smaller than the coefficient of the variable $LAX\_REGULATION_{j,t-1}$.

The negative and significant coefficients of the variable $CDS\_SOVEREIGN_{j,t-1}$ show that banks in countries with higher CDS spreads, corresponding to high country risk, are associated with decreasing RWA densities after the switch to the IRB approach.[40] These results suggest that especially for banks in high-risk countries, the RWA density does not seem to reflect anymore realistically the country risk, thereby underestimating banks' actual economic risk position. Moreover, the coefficient of the respective interaction term $HIGH\_RISK_{j,t-1} \times IRB_{i,j,t-1}$ is positive but no statistically significant. Overall, our results show the differences in regulators' response to the initial reduction in RWA density described by Mariathasan and Merrouche (2014) in the different country groups.

[39] We test the robustness of these findings estimating Equation (2) for different subsamples. Macroeconomic shocks and regulation changes to further stabilize the financial sector, as presented in the Internet Appendix A.3, motivate the choice of these subsamples. The results are presented in Internet Appendix F. As the 2008 world financial crisis has substantially affected banks across countries, the subsample reported in Table A.28 starts after the end of the crisis in the third quarter of 2009 and includes the time period until the end of the sample period. Besides, we create a subsample including both the financial crisis and the sovereign debt crisis. Table A.29 reports the results for this subsample starting in 2007 until the end of 2012 and isolates the time period where banks switched to the IRB approach from subsequent periods. On the contrary, the macroeconomic situation in Europe in the years between 2013 and 2019 has been stable. Table A.30 reports the results based on the subsample that isolates this recent development.

[40] To test for potential differences between sovereign credit risk and bank-specific risk, we use banks' CDS spreads instead of sovereign CDS spreads. The results reported in Table A.31 in the Internet Appendix are largely in line with our main results and confirm the robustness of our conclusions.

Table 5: Cross-sectional analysis: including country indicators.

	Dependent variable: $\varnothing\Delta RWAD_{i,j}^{s+r}$				
	$r = 8$	$r = 16$	$r = 24$	$r = 32$	$r = 40$
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
AUSTRIA	0.632	0.869	1.273*	0.876	−0.378
	(1.393)	(1.046)	(0.752)	(1.061)	(0.761)
BELGIUM	0.366	0.447	0.350	−0.357	−1.211***
	(0.916)	(0.693)	(0.518)	(0.907)	(0.255)
DENMARK	−4.807***	−1.578**	−0.601	−1.231	−1.998***
	(1.140)	(0.673)	(0.644)	(1.007)	(0.409)
FINLAND	−3.048**	−0.419	−0.637	−1.231	−2.214***
	(1.526)	(0.814)	(0.575)	(0.968)	(0.342)
FRANCE	0.106	1.210**	0.749	−0.029	−0.776***
	(0.738)	(0.535)	(0.534)	(0.930)	(0.260)
GERMANY	−2.744***	0.511	0.135	−0.101	−0.621
	(0.957)	(0.643)	(0.914)	(1.193)	(0.526)
IRELAND	−1.419	−0.317	−0.040	0.161	−1.036*
	(1.035)	(0.570)	(0.819)	(1.022)	(0.577)
ITALY	−1.965	0.305	0.280	−0.837	−1.712***
	(1.310)	(0.772)	(0.738)	(0.938)	(0.382)
NORWAY	−2.925	0.365	1.297	0.602	−0.415
	(1.973)	(0.793)	(1.674)	(1.806)	(1.349)
SPAIN	−2.074*	−0.259	0.221	−0.252	−1.041
	(1.161)	(0.730)	(0.895)	(1.102)	(0.650)
SWEDEN	−0.315	−0.975	−1.579***	−2.399**	−2.633***
	(1.505)	(0.859)	(0.576)	(1.014)	(0.442)
SWITZERLAND	1.109	1.677***	1.994***	1.165	0.532*
	(0.949)	(0.474)	(0.639)	(1.016)	(0.318)
UK	0.111	0.881	0.800	0.051	−0.963***
	(1.004)	(0.542)	(0.562)	(0.935)	(0.267)
$PRE\_CRISIS_{i,j}$	1.868**	1.060**	0.627	1.007*	0.215
	(0.877)	(0.444)	(0.442)	(0.592)	(0.355)
$\varnothing RWAD_{i,j}$	0.089	0.003	−0.035	−0.041	−0.036
	(0.081)	(0.040)	(0.061)	(0.053)	(0.044)
$\varnothing EQUITY_{i,j}$	−0.502	−0.008	0.220	0.104	0.129
	(0.395)	(0.182)	(0.303)	(0.274)	(0.213)
$\varnothing SIZE_{i,j}$	−0.102	−0.160	−0.056	−0.106	−0.125
	(0.435)	(0.227)	(0.211)	(0.168)	(0.124)
Constant	−1.230	−0.160	−0.629	1.271	2.740
	(6.774)	(3.567)	(3.270)	(2.672)	(1.993)
Observations	50	49	48	46	41
R^2	0.624	0.512	0.493	0.539	0.639
Adjusted R^2	0.425	0.244	0.206	0.260	0.371
Residual Std. Error	1.690 (df = 32)	0.997 (df = 31)	1.013 (df = 30)	0.951 (df = 28)	0.700 (df = 23)
F Statistic	3.130*** (df = 17; 32)	1.910* (df = 17; 31)	1.718* (df = 17; 30)	1.928* (df = 17; 28)	2.390** (df = 17; 23)

This table reports regression results of the cross-sectional analysis with robust standard errors in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Key variables: $\varnothing\Delta RWAD_{i,j}^{s+r}$ is calculated as the average change in bank i's risk-weighted assets to total assets across r quarters after the quarter of switch s in percent. The country variables are indicator variables equal to 1 if a bank is headquartered in this country and 0 otherwise. Comprehensive variable descriptions of all other variables are provided in Table A.7 in the Internet Appendix.

Table 6: Baseline results of the panel analysis.

	Dependent variable: $\Delta RWAD_{i,j,t}$			
	(1)	**(2)**	**(3)**	**(4)**
$LAX\_REGULATION_{j,t-1} \times IRB_{i,j,t-1}$		1.765*		
		(1.032)		
$STRICT\_SUPERVISION_{j,t-1} \times IRB_{i,j,t-1}$			2.970***	
			(1.105)	
$CDS\_SOVEREIGN_{j,t-1} \times IRB_{i,j,t-1}$				0.207
				(0.544)
$LAX\_REGULATION_{j,t-1}$	-0.622**	-2.305**	-0.509*	-0.625**
	(0.305)	(1.054)	(0.294)	(0.304)
$STRICT\_SUPERVISION_{j,t-1}$	0.0802	0.106	-2.607**	0.0771
	(0.225)	(0.233)	(1.047)	(0.228)
$CDS\_SOVEREIGN_{j,t-1}$	-0.769***	-0.819***	-0.813***	-0.958*
	(0.285)	(0.290)	(0.292)	(0.549)
$IRB_{i,j,t-1}$	1.231*	0.312	0.226	0.545
	(0.625)	(0.643)	(0.506)	(2.130)
$G\_SIB_{i,j,t}$	0.353	0.489	0.263	0.355
	(0.385)	(0.370)	(0.363)	(0.384)
$\Delta LOANS_{i,j,t-4}$	-0.0275	-0.0266	-0.0265	-0.0277
	(0.0263)	(0.0265)	(0.0266)	(0.0264)
$\Delta RETURN\_ON\_RWA_{i,j,t-4}$	0.510	0.495	0.501	0.511*
	(0.305)	(0.308)	(0.308)	(0.305)
$\Delta LLR_{i,j,t-4}$	-0.232	-0.233	-0.219	-0.234
	(0.473)	(0.471)	(0.477)	(0.472)
$\Delta EQUITY_{i,j,t-4}$	1.232**	1.251**	1.244**	1.230**
	(0.510)	(0.509)	(0.508)	(0.509)
$SIZE_{i,j,t-4}$	0.519	0.521	0.671	0.529
	(0.511)	(0.511)	(0.499)	(0.507)
$DOMESTIC\_CREDIT_{j,t-4}$	0.00941	0.00867	0.0101	0.00924
	(0.00681)	(0.00653)	(0.00679)	(0.00687)
$\Delta GDP_{j,t-4}$	0.125*	0.122*	0.128**	0.126*
	(0.0626)	(0.0625)	(0.0605)	(0.0625)
q2	0.783	0.780	0.778	0.784
	(0.741)	(0.742)	(0.743)	(0.741)
q3	0.387	0.363	0.366	0.394
	(0.618)	(0.618)	(0.622)	(0.621)
q4	0.955	0.934	0.938	0.962
	(1.326)	(1.326)	(1.327)	(1.328)
Bank and quarter-fixed effects	Yes	Yes	Yes	Yes
Observations	2,231	2,231	2,231	2,231
R^2	0.109	0.111	0.114	0.109
Adjusted R^2	0.0846	0.0858	0.0892	0.0843

This table reports regression results of the panel analysis with robust standard errors in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Key variables: $\Delta RWAD_{i,j,t}$ is calculated as the quarterly change in bank i's risk-weighted assets to total assets in percent. $LAX\_REGULATION_{j,t}$ ($STRICT\_SUPERVISION_{j,t}$) is an indicator variables equal to 1 if country j is classified as country with less strict regulation (strict supervision) and 0 otherwise. $CDS\_SOVEREIGN_{j,t}$ is defined as the natural logarithm of country j's sovereign credit-default swap spreads. $IRB_{i,j,t}$ is an indicator variable equal to 1 if bank i uses the internal ratings-based approach in a quarter and 0 otherwise. Comprehensive variable descriptions of all other variables are provided in Table A.8 in the Internet Appendix.

Before switching to the IRB approach, banks' RWA densities across countries could be clearly grouped accordingly to sovereign risk. As shown in Table 1, the average RWA density at the quarter of the switch of banks headquartered in Ireland, Italy, and Spain are among the highest across countries. Whereas for Irish and Spanish banks, we observe a large drop in RWA densities five years after switching, those of Italian banks decrease even more between five and ten years after the switch. Since the purpose of IRB approach regulations is to increase risk sensitivity compared to the standardized approach, one would expect the dispersion of RWA densities across countries to further increase after the switch.[41] With reference to the country grouping, our results show that on long term, RWA densities of banks adopting the IRB approach converge despite differences in sovereign credit risk and of regulatory and supervisory strictness.

Interestingly, the coefficients of the variable $IRB_{i,j,t-1}$ are positive and significant in at least in column (1). As most banks switch at the beginning of the sample period, the variable may be partially influenced by the overall increasing minimum capital requirements and the introduction of a risk weight floor for banks with the approval to use the IRB approach in some countries.[42]

The coefficients of $\Delta RETURN\_ON\_RWA_{i,j,t-4}$ are positive and statistically significant at least in column (4). This result suggests that an increase in profitability creates further incentives for banks to increase their RWA densities. Banks may aim to further increase their profitability based on more risky business activities requiring higher risk weights, hence more equity capital. This is in line with earlier studies that provide evidence that retained earnings are the main source of increasing RWA densities (e.g., Cohen, 2013). Moreover, the coefficients of the variable $\Delta EQUITY_{i,j,t-4}$ are positive and significant in all four columns. Banks with an increasing share of equity, marginally increase their RWA densities.

Alternatively, as a response to increasing bank profitability, regulators may boost capital requirements, which ultimately leads to positive RWA density adjustments. The introduction of higher capital requirements in Norway in 2013 may serve as an example (Juelsrud and Wold, 2020). A regulator would prefer this to drastic changes in lending policy that may have a negative impact on credit supply. This is even more plausible as these changes would typically occur in regimes of low economic growth, when regulators must avoid radical measures that may reduce households' and businesses' ability to borrow.

With regard to the seasonal variation of RWA densities, the coefficients of the quarter indicators for columns (1) to (3) are positive, confirming the seasonality across quarters, as capital from profit builds up during the year, but is typically disbursed only annually through dividends.

Please also note, that the variable $\Delta LOANS_{i,j,t-4}$ is insignificant in all four columns. As mentioned for example by Hoshi and Wang (2021), one alternative explanation of convergence is actual convergence in banks' portfolio allocations. By introducing this

[41] Yet, as shown in Table A.3, the standard deviation of banks' RWA density decreases across years and the downward trend is mainly influenced by a decrease in maximum values.

[42] As a robustness test, we use the variable $IRB\_COVERAGE_{i,j,t-1}$ instead of $IRB_{i,j,t-1}$ and report the results in Table A.32 in the Internet Appendix. Whereas the results are very similar, the coefficients of the variable $IRB\_COVERAGE_{i,j,t-1}$ are negative and statistically significant in column (4), suggesting that more progress in implementing the IRB approach helps banks in high-risk countries to further reduce their RWA densities.

variable, we control for changes in banks' portfolio allocation. Moreover, we use the variable corporate loan share as an alternative measure of banks' asset composition.[43] Hence, the convergence does not seem to be solely a results of changes in the banks' asset composition.

In the euro area, the introduction of the Single Supervisory Mechanism in 2014 assigned the ECB to be directly responsible for the most significant institutions, whereas supervision of less significant ones remains with the national supervisors (ECB, 2018). Due to the large share of euro banks in our data set, we subdivide the full sample into banks headquartered in euro countries, which belong to the European Banking Union, and non-euro countries.[44] Tables 7 and 8 presents the subsample analysis results which reveal interesting differences between the two samples and help to explain the overall effects.

The negative and significant coefficient of $LAX\_REGULATION_{j,t-1}$ and the positive and significant coefficient of $STRICT\_SUPERVISION_{j,t-1}$ in Table 8 show that regulatory and supervisory strictness are important factors influencing the RWA density change outside of the euro area. In contrast, especially due to the Single Supervisory Mechanism, the regulatory framework in the euro area is very similar and does not give rise to large differences across banks and countries. In Table 7, the coefficient of the variable $CDS\_SOVEREIGN_{j,t-1}$ is negative and statistically significant, suggesting that banks in euro countries associated with high country risk show decreasing RWA densities. These results confirm that RWA densities cease to map banks' full country risk, hereby underestimating their actual economic risk. Compared to the RWA densities of banks in countries with lower CDS spreads and respectively lower risk, RWA densities of banks in countries with high CDS spreads gradually decrease despite consistently higher levels of risk.

The positive and significant coefficients of the variable $\Delta EQUITY_{i,j,t-4}$ in Table 7 further suggest that in the euro area especially large banks with an increasing share of equity are associated with increasing RWA densities over time. With respect to the non-euro subsample reported in Table 8, the positive and significant coefficients of $RETURN\_ON\_RWA_{i,j,t-4}$ and $DOMESTIC\_CREDIT_{j,t}$ indicate that especially regulators outside of the European Banking Union take into account bank resilience to ensure sufficient credit supply to the economy.

In summary, our analysis provides evidence on why banks' RWA densities converge to a lower level over time, compared to 2007, before the switch to the IRB approach. Whereas banks' RWA densities before the switch have been largely corresponding to sovereign risk, introducing the more risk-sensitive IRB approach seems to promote convergence of RWA densities across banks and countries. Even though this approach should even more closely map bank-specific risk, we solely observe high RWA densities of banks in high-risk countries shortly after the switch, which are decreasing over time. On the contrary, banks in countries with strict supervision increase their RWA densities in the long term and in particular in recent years, corresponding to higher capital requirements implemented by

[43] The robustness check reported in Table A.33 in the Internet Appendix shows that the asset composition does not explain RWA density convergence over time.

[44] In our data set, countries outside of the euro area include Denmark, Norway, Sweden, Switzerland, and the UK.

Table 7: Panel analysis: euro subsample.

	Dependent variable: $\Delta RWAD_{i,j,t}$			
	(1)	**(2)**	**(3)**	**(4)**
$LAX\_REGULATION_{j,t-1} \times IRB_{i,j,t-1}$		0.975 (1.144)		
$STRICT\_SUPERVISION_{j,t-1} \times IRB_{i,j,t-1}$			1.775 (1.068)	
$CDS\_SOVEREIGN_{j,t-1} \times IRB_{i,j,t-1}$				1.078* (0.590)
$LAX\_REGULATION_{j,t-1}$	0.0556 (0.357)	-0.859 (1.201)	0.110 (0.347)	0.0566 (0.355)
$STRICT\_SUPERVISION_{j,t-1}$	-0.194 (0.238)	-0.177 (0.245)	-1.763* (0.998)	-0.203 (0.249)
$CDS\_SOVEREIGN_{j,t-1}$	-0.833** (0.387)	-0.886** (0.379)	-0.805** (0.363)	-1.961*** (0.669)
$IRB_{i,j,t-1}$	1.331* (0.736)	0.711 (0.848)	0.618 (0.591)	-2.420 (2.504)
$G\_SIB_{i,j,t}$	0.673 (0.412)	0.798* (0.431)	0.574 (0.382)	0.681* (0.399)
$\Delta LOANS_{i,j,t-4}$	-0.0381 (0.0328)	-0.0373 (0.0331)	-0.0367 (0.0333)	-0.0393 (0.0328)
$\Delta RETURN\_ON\_RWA_{i,j,t-4}$	0.202 (0.365)	0.193 (0.368)	0.197 (0.367)	0.204 (0.368)
$\Delta LLR_{i,j,t-4}$	-0.442 (0.534)	-0.445 (0.533)	-0.442 (0.536)	-0.451 (0.528)
$\Delta EQUITY_{i,j,t-4}$	1.235** (0.529)	1.244** (0.527)	1.242** (0.527)	1.222** (0.526)
$SIZE_{i,j,t-4}$	0.728 (0.481)	0.688 (0.484)	0.812 (0.493)	0.806 (0.489)
$DOMESTIC\_CREDIT_{j,t-4}$	-0.00490 (0.00626)	-0.00496 (0.00625)	-0.00443 (0.00621)	-0.00474 (0.00627)
$\Delta GDP_{j,t-4}$	0.100** (0.0447)	0.101** (0.0442)	0.108** (0.0430)	0.100** (0.0432)
q2	1.161 (1.092)	1.155 (1.094)	1.168 (1.095)	1.149 (1.093)
q3	0.737 (1.004)	0.710 (1.003)	0.752 (1.009)	0.714 (1.007)
q4	2.208 (1.901)	2.181 (1.902)	2.223 (1.903)	2.184 (1.901)
Bank and quarter-fixed effects	Yes	Yes	Yes	Yes
Observations	1,312	1,312	1,312	1,312
R^2	0.131	0.132	0.134	0.134
Adjusted R^2	0.0896	0.0894	0.0913	0.0918

This table reports regression results of the panel analysis with robust standard errors in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Key variables: $\Delta RWAD_{i,j,t}$ is calculated as the quarterly change in bank i's risk-weighted assets to total assets in percent. $LAX\_REGULATION_{j,t}$ ($STRICT\_SUPERVISION_{j,t}$) is an indicator variables equal to 1 if country j is classified as country with less strict regulation (strict supervision) and 0 otherwise. $CDS\_SOVEREIGN_{j,t}$ is defined as the natural logarithm of country j's sovereign credit-default swap spreads. $IRB_{i,j,t}$ is an indicator variable equal to 1 if bank i uses the internal ratings-based approach in a quarter and 0 otherwise. Comprehensive variable descriptions of all other variables are provided in Table A.8 in the Internet Appendix.

Table 8: Panel analysis: non-euro subsample.

	Dependent variable: $\Delta RWAD_{i,j,t}$			
	(1)	**(2)**	**(3)**	**(4)**
$LAX\_REGULATION_{j,t-1} \times IRB_{i,j,t-1}$		10.04*** (1.393)		
$STRICT\_SUPERVISION_{j,t-1} \times IRB_{i,j,t-1}$			8.171*** (2.206)	
$CDS\_SOVEREIGN_{j,t-1} \times IRB_{i,j,t-1}$				-4.289** (1.667)
$LAX\_REGULATION_{j,t-1}$	-1.375*** (0.392)	-11.20*** (1.333)	-1.093*** (0.357)	-1.213*** (0.368)
$STRICT\_SUPERVISION_{j,t-1}$	0.983** (0.425)	1.215*** (0.404)	-6.936*** (2.203)	1.159** (0.408)
$CDS\_SOVEREIGN_{j,t-1}$	-1.128 (0.868)	-1.488* (0.838)	-1.400 (0.857)	2.857 (1.851)
$IRB_{i,j,t-1}$	2.338 (1.788)	0.999 (1.023)	0.828 (0.997)	14.87** (5.982)
$G\_SIB_{i,j,t}$	-0.0778 (0.659)	-0.0715 (0.629)	-0.186 (0.634)	-0.0399 (0.649)
$\Delta LOANS_{i,j,t-4}$	-0.0139 (0.0386)	-0.0159 (0.0391)	-0.0184 (0.0384)	-0.0152 (0.0386)
$\Delta RETURN\_ON\_RWA_{i,j,t-4}$	1.287* (0.676)	1.248* (0.680)	1.289* (0.666)	1.257* (0.672)
$\Delta LLR_{i,j,t-4}$	0.630 (0.859)	0.711 (0.846)	0.731 (0.841)	0.710 (0.821)
$\Delta EQUITY_{i,j,t-4}$	1.351 (1.141)	1.396 (1.142)	1.355 (1.138)	1.379 (1.145)
$SIZE_{i,j,t-4}$	0.516 (1.097)	0.320 (1.032)	0.698 (1.068)	0.495 (1.044)
$DOMESTIC\_CREDIT_{j,t-4}$	0.0684*** (0.0165)	0.0560*** (0.0140)	0.0579*** (0.0138)	0.0622*** (0.0147)
$\Delta GDP_{j,t-4}$	0.234 (0.184)	0.147 (0.184)	0.169 (0.179)	0.152 (0.180)
q2	0.508 (0.970)	0.467 (0.984)	0.466 (0.978)	0.472 (0.980)
q3	0.132 (0.916)	0.00863 (0.903)	0.0549 (0.897)	0.0269 (0.914)
q4	-0.234 (1.760)	-0.332 (1.766)	-0.299 (1.768)	-0.313 (1.749)
Bank and quarter-fixed effects	Yes	Yes	Yes	Yes
Observations	919	919	919	919
R^2	0.163	0.180	0.177	0.173
Adjusted R^2	0.105	0.122	0.118	0.114

This table reports regression results of the panel analysis with robust standard errors in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Key variables: $\Delta RWAD_{i,j,t}$ is calculated as the quarterly change in bank i's risk-weighted assets to total assets in percent. $LAX\_REGULATION_{j,t}$ ($STRICT\_SUPERVISION_{j,t}$) is an indicator variables equal to 1 if country j is classified as country with less strict regulation (strict supervision) and 0 otherwise. $CDS\_SOVEREIGN_{j,t}$ is defined as the natural logarithm of country j's sovereign credit-default swap spreads. $IRB_{i,j,t}$ is an indicator variable equal to 1 if bank i uses the internal ratings-based approach in a quarter and 0 otherwise. Comprehensive variable descriptions of all other variables are provided in Table A.8 in the Internet Appendix.

the national authorities. Hence, jurisdiction-specific differences in banking regulation and supervision partially explain banks' RWA density changes.

All in all, despite existing differences in sovereign risk across countries, we observe downward convergence of the RWA densities of European banks over time. On the one hand, the observed RWA density convergence may be due to positive factors where it mirrors more homogeneity across banks and countries. Banks may adjust their portfolio composition and mitigate the risk of their business activities to reduce their RWA to meet the increasing capital requirements. On the other hand, opportunities for regulatory arbitrage may explain the negative aspects of this convergence. Banks in countries with high country risk reduce their RWA densities despite high supervisory power, as authorities may refrain from imposing restrictive supervision. Introducing regulatory requirements above the level the average bank in a country can comply with, would lead to the counterproductive effect of destabilizing the banking sector. Hence, regulatory authorities have an incentive to relax regulations to a level that leads to a build up of RWA densities, reflecting both the national banking sectors' ability and the perceived level of risk. Even though the gradual implementation of the IRB approach provides incentives for moral hazard, our results show that the roll-out process or banks' asset composition does not explain our findings.

6 Conclusion and policy implications

As per regulatory intention, internal credit risk models are intended to render banks' RWAs more risk sensitive. The IRB approach is aimed at aligning capital and risk levels and increase the banks' focus on risk management and transparency. Thus, after the adoption of the IRB approach, one would expect the dispersion of RWA densities across banks to increase. Yet, we observe a downward convergence of RWA densities across banks and countries over time. To the best of our knowledge, this is the first study in the literature that sheds light on the dispersion of RWA densities across countries and in particular on their development over time.

Our analysis is based on quarterly data of 52 listed banks headquartered in 14 European countries from Q1/2007 to Q4/2019. We study the differences in RWA density changes across countries and groups after the switch to the IRB approach, and identify the factors impacting their development over time. We investigate both country- and bank-specific factors.

First, we introduce a grouping based on several country-specific factors, not only considering sovereign risk, as is common in prior studies, but also based on national banking regulation and supervision.

Second, we observe a decrease in RWA densities immediately after the switch, causing different reactions of national supervisory authorities across country groups. Especially authorities in countries with strict regulation or supervision reacted to the initial drop in RWA densities by imposing regulations that increased RWA densities. By contrast, authorities in high-risk countries seem to have allow a degree of leeway in IRB capital requirement calculations, which explains the gradual decrease in RWA densities over time for this country group.

Third, with respect to the development of RWA densities over time, we show that they converge to a lower level than the values prior to the switch to the IRB approach.

Especially for banks in countries with high country risk and high initial levels of RWA densities, we observe a more significant reduction over time. For example, while the initial reduction in RWA density is large in countries with less stringent regulations or in countries with strict supervision, there is a significant countereffect after IRB approach implementation. In high-risk countries, there is no such countereffect. Moreover, results suggest that authorities do not seem to impose strict supervision in countries with high risk and for low-profitability banks, as these may not be able to cope with high minimum capital requirements. In contrast, banks in countries with strict regulation and/or supervision increase their RWA densities, especially in recent years.

The main objective of regulatory authorities is to foster financial stability and provide a strong and resilient banking system to support sustainable economic growth. Our results suggest that prior negative effects of banking crises on society may have affected regulatory policies of imposing higher minimum capital requirements. We discuss factors that facilitate the enforcement of strict regulations without negatively affecting the supply of credit in a downturn. For example, competition among banks in a country fosters strict regulations. However, it remains an open question whether the convergence is mainly driven by bank behavior, namely regulatory arbitrage, or supervisory forbearance or both. Further disentangling these different (yet not mutually exclusive) narratives provides an interesting starting point for future research, but would require more detailed data on the actions taken of banks and supervisors, as well as their underlying motives.

Overall, our results show that the adoption of the IRB approach reduces differences in RWA densities between countries, which makes internal models less suitable fot reflecting the country-specific risk factors. Internal credit risk models are intended to map the risk in each institution more effectively than the standardized approach, yet, a downward convergence in risk across countries is counter intuitive.

As a response to growing criticism of internal model-based regulations, especially regarding the lack of transparency, the Basel Committee suggests restricting their use. Thus, the committee proposes to introduce an output floor for IRB capital requirements of 72.5% of the capital requirements calculated based on the standardized approach (BCBS, 2017). However, output floors on minimum capital levels in the IRB frame should be determined with caution, as extensively high pre-imposed levels might have the countereffect of leaving banks less room for maneuver, which would ultimately lead to the RWA density convergence across banks, failing to reflect the actual level of economic risk.

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