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ORIGINAL PAPER

Revisiting Basel risk weights: cross-sectional risk sensitivity and cyclicality

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Abstract We empirically assess the sensitivity of Basel risk weights to bank portfolio risk and the business cycle. With our econometric model, we distinguish between cross-sectional risk sensitivity and longitudinal risk sensitivity (cyclicality) of the regulatory standard. Employing a comprehensive data set covering 200 large banks from 28 countries, we find that actual risk weights are fairly insensitive to the business cycle. There is no evidence that Basel II has significantly increased cyclicality. Furthermore, cross-sectional risk sensitivity of regulatory risk weights to a market measure of bank portfolio risk is low. We further assess the adequacy of the capital standard's risk sensitivity based on a Merton-style model of bank risk and bank default. Judged upon the Basel Committee's self-established goal of maintaining bank default rates below 0.1 %, our results suggest that risk weights and minimum capital requirements are ill-calibrated, even under the stricter Basel III rules.

Keywords Basel II · Risk weights · Banking regulation · Capital requirements · Pro-cyclicality

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1 Introduction

Risk-weighting is the cornerstone of the current capital adequacy regulation. Starting with the Basel I Accord in 1988, which defined a set of five simple risk weights for credit exposures, the regulation has become increasingly complex. The 1996 Market Risk Amendment established an internal models approach for treating market risk, and the Basel II package of reforms in 2004 introduced an internal ratings-based (IRB) formula to derive risk-weighted assets (RWA) for credit risk exposures. These enhancements to the framework were designed with the objective of making risk weights more sensitive to the underlying risks within bank portfolios. Yet the journey is not over: while Basel III focused on the quality and quantity of the regulatory capital base, the Basel Committee on Banking Supervision is now revising the regulatory assessment of credit and market risk ("Basel IV").

While higher capital ratios generally increase banks' resilience, i.e., the probability of survival during financial turmoil (Berger and Bouwman 2013), the theoretical and empirical literature on the adequacy of capital regulation raises concerns over Basel's risk-based capital ratios. First, despite the continuous increase in the complexity of risk weights, their risk sensitivity—that is, their effectiveness in reflecting banks' actual portfolio risk and predicting financial health—seems to be limited (Demirguc-Kunt et al. 2013; Vallascas and Hagendorff 2013). Second, while bank activities are inherently pro-cyclical, capital requirements based on risk-weighting is believed to exacerbate banks' pro-cyclical behavior (Kashyap and Stein 2004; Gordy and Howells 2006; Heid 2007, among many others).[1] The reasoning behind this proposition is as follows: When the economy is in the trough of the business cycle, risk measures and hence RWA tend to increase, resulting in higher capital requirements. As it tends to be difficult to raise capital in recessions, banks may be forced to reduce their lending activities, thereby amplifying shocks in the real sector.[2]

In this paper, we aim to investigate the extent of both risk sensitivity and cyclicality of Basel risk weights. Both issues are inseparably interrelated: risk weights may change either due to differing bank portfolio risks at a point in time or due to changes in the economic environment through the cycle. If risk weights are adjusted to changes in portfolio risk through the business cycle, risk sensitivity inherently creates cyclicality. We therefore make a clear distinction between (1) the *cross-sectional sensitivity* of risk weights to individual banks' risk at a point in time, and (2) the *longitudinal sensitivity* of risk weights to risk over the business cycle (Kashyap and Stein 2004). While the former is frequently considered as a desirable feature of capital regulation (Basel Committee on Banking Supervision 2013c), the

[1] While "cyclicality" of the capital regulation refers to adjustments of RWA and hence capital requirements to the business cycle, "pro-cyclicality" is usually used in reference to the amplification of the economic cycle by the dynamic interactions between the financial and the real sectors of the economy (Financial Stability Board 2009).

[2] In order to account for the perceived pro-cyclicality of the capital requirements, Basel III has introduced a counter-cyclical capital buffer above the regulatory minimum requirement. The buffer size is governed in a counter-cyclical manner according to variations in systemic risk to dampen the pro-cyclicality of bank lending.

latter (cyclicality) is seen as a potential threat to financial stability (Financial Stability Board 2009).

Our contribution to the existing literature on risk sensitivity and cyclicality of the capital adequacy regulation is threefold. First, we present a theoretical model for the relation of cross-sectional and longitudinal sensitivity of risk weights. In doing so, we introduce a simple measure for each type of sensitivity. Second, we empirically assess the sensitivity of risk weights to bank portfolio risk and the business cycle by applying our model to a comprehensive data set covering 200 large banks from 28 countries. We find that the cyclicality of Basel risk weights is low. Moreover, contrary to expectations, we find no evidence that the implementation of Basel II has increased cyclicality. Third, we assess the adequacy of the measured risk sensitivity from a regulator's perspective. We estimate empirical risk curves describing the relation between RWA and actual bank portfolio risk. Based on a Merton-style model of bank risk and bank default, we contrast these empirical risk curves with theoretical curves. We conclude that, in context of the current level of minimum regulatory capital requirements, the cross-sectional risk sensitivity is not sufficient. Even under the increased Basel III capital requirements, the current standard may lead to bank default probabilities far above acceptable levels, especially in times of financial turmoil.

The paper proceeds as follows. The next section reviews the existing body of relevant literature. Section 3 presents our theoretical model, its empirical estimation procedure, and the data sample. Section 4 reports the main results on the model estimations for cross-sectional and longitudinal risk sensitivity alongside additional robustness analyses. In Sect. 5 we assess the adequacy of the measured risk sensitivity. Section 6 concludes.

2 Relation to the literature

Regarding the effectiveness of risk-based capital regulation, the literature raises concerns over Basel's risk-based capital ratios' risk-taking incentives and their weak ability to predict banks' financial health. Haldane (2012), among others, criticizes the complexity and over-parameterization of the (internal model-based) risk parameter estimates. In this context, several studies question the consistency of risk weights across banks. The Basel Committee on Banking Supervision (2013a, b) documents in their "Regulatory Consistency Assessment Programme" a considerable variation across banks in average risk weights that reflects modeling choices and supervisory decisions and not only risk taking. Likewise, the European Banking Authority (2013a) states that risk weights are driven by both risk- and non-risk-based drivers. Furthermore, using supervisory data on loans for U.S. banks, Firestone and Rezende (2015) document a substantial dispersion in PD and LGD estimates.

Even worse, RWA are suspected of being subject to banks' strategic risk-modeling. Mariathasan and Merrouche (2014) report a decline in RWA upon IRB approval. The decline is particularly pronounced among weakly capitalized banks and in countries with weak legal frameworks for supervision, leading the authors to the conclusion that banks knowingly under-report risk. In this connection, Hellwig (2010) claims that risk calibration was mainly a tool to reduce capital requirements. Effectively, Basel II was so designed that the use of banks' internal models would allow them to derive lower risk weights in order to incite banks to enhance their risk management practices. Empirically, Basel II banks indeed exhibit lower RWA and hence lower capital charges than under Basel I (Antão and Lacerda 2011; Le Leslé and Avramova 2012; Mariathasan and Merrouche 2014).

Finally, despite the increase in regulatory complexity, there is evidence that the current standard still does not sufficiently reflect banks' actual portfolio risk. Haldane (2012) shows for a set of large global banks that an unweighted leverage ratio appears to have greater predictive power for distinguishing between failed and surviving banks than risk-weighted alternatives. Similarly, Demirguc-Kunt et al. (2013) report that a simple leverage ratio outperformed risk-based ratios in predicting banks' stock price performance during the financial crisis. Furthermore, Acharya et al. (2014) compare the capital shortfall measured by regulatory stress tests and show that the regulatory risk weights of stress tests have no link with the realized risk of banks during a crisis.

Papers in this vein most closely related to our study are Barakova and Palvia (2014) and Vallascas and Hagendorff (2013). Barakova and Palvia (2014) examine the relation of RWA and a range of accounting and market-based risk measures. They document stronger correlations of accounting risk measures (e.g., loan performance) with Basel II risk weights than with Basel I risk weights. There is similar but weaker evidence for market-based measures (e.g., bond spread, equity volatility). Vallascas and Hagendorff (2013) analyze the degree to which RWA reflect the actual portfolio risk of a bank, defined by its asset volatility as a market-based measure of risk. They find a positive but rather weak association between regulatory risk weights and banks' asset volatility. Moreover, Basel II has only marginally improved this risk sensitivity.

However, in measuring risk sensitivity, Vallascas and Hagendorff (2013) do not distinguish between the cross-sectional and longitudinal sensitivity of risk weights. This could lead to severe underestimation: for example, if the regulatory standard was fully risk-sensitive in the cross section but insensitive to the business cycle, an aggregate global measure of risk sensitivity would be very low. In this context, we extend the approach of Vallascas and Hagendorff (2013) by separating cross-sectional and longitudinal sensitivity. As a result, we can distinguish between the desired feature of effectively measuring the risk exposure of individual banks at a point in time and the potentially problematic feature of varying risk weights through the cycle.

Regarding such cyclicality, a large body of literature raises concerns about the pro-cyclical effects of Basel II. Studies on this subject can be classified into three categories: first, various papers perform numerical simulations on hypothetical or real world portfolios based on the IRB formula to analyze the peak-to-trough variation of capital requirements (e.g., Kashyap and Stein 2004; Goodhart et al. 2004; Altman et al. 2005; Gordy and Howells 2006; Saurina and Trucharte 2007; Repullo et al. 2010; Andersen 2011). Overall, these studies document a significant variability of the risk weights through the business cycle, particularly for point-in-time rating systems. Although Gordy and Howells (2006) remain skeptical that pro-cyclicality in Basel II requires corrective measures, they discuss two basic approaches for mitigating the potential cyclicality: the input of the RWA formula may be smoothed by using some sort of through-the-cycle adjustment, or the output could be smoothed by using some adjustment of the resulting RWA. Referring to the latter alternative, Kashyap and Stein (2004) argue that the capital standard should feature a family of risk curves to tolerate a greater probability of default when economy-wide bank capital is scarce relative to lending opportunities. Second, several papers design theoretical models to analyze how Basel II would affect banks' behavior and the pro-cyclicality of the banking system (e.g., Catarineu-Rabell et al. 2005; Angelini et al. 2010; Repullo and Suarez 2013). In general, these papers confirm the conclusion from the simulation results that Basel II is likely to increase pro-cyclicality. Third, few more recent studies utilize data from the years after the introduction of Basel II to analyze reported risk weights during the business cycle. Using supervisory data for Italian banks, Cannata et al. (2011) confirm the assumption that Basel II is cyclical: Risk weights for credit risk increased during the financial crisis, particularly for IRB exposures. However, variations are rather low compared to the concurrent substantial increase in market wide risk. The European Banking Authority (2013b) analyzes the development of RWA for 60 European banks and finds that risk weights even declined for most of the investigated portfolios during and after the 2008 financial crisis, partly attributable to a shift towards portfolios with lower risk profiles. They conclude that evidence on pro-cyclicality of capital requirements is weak and there is no clear causal link between capital requirements regulation and the economic cycle.

To sum up, while simulation studies and theoretical models predict a significant pro-cyclicality of Basel II risk weights, there is some evidence that the actual cyclicality is less severe. However, research on "realized" cyclicality is still limited. A central aim of this paper is to add to the evidence for the actual cyclicality of the regulatory standard. While the cited studies only report singular results for a limited number of banks by comparing a crisis and a non-crisis phase, we present a comprehensive study with an integrated model. As discussed, our model separates cyclicality from cross-sectional risk sensitivity. The data sample used to estimate the model and gain empirical results covers banks from 28 countries around the world and a period of 14 years, which also includes the financial crisis.

3 Methodology and sample

3.1 Regulatory and economic risk measures

Following Vallascas and Hagendorff (2013) and Barakova and Palvia (2014), we consider the risk sensitivity of a regulatory standard as the relation of a regulatory risk measure to an economic risk measure. The natural regulatory risk measure is the ratio of RWA over total assets, TA, i.e. the "risk-weight density", RWD (Le Leslé and Avramova 2012):

$$RWD_{i,t} = \frac{RWA_{i,t}}{TA_{i,t}}, \tag{1}$$

where the indices refer to a bank i at time t. Given the solvability ratio of 8 %, the RWA are 12.5 times the regulatory capital requirements for a particular bank, aggregated over all risk classes (credit risk, market risk, and operational risk).

For the economic risk measure, in line with Vallascas and Hagendorff (2013), we consider the bank's asset volatility. As a market-implied risk measure, asset volatility not only reflects asset and liability returns, but also off-balance sheet and operational risk (Flannery and Sorescu 1996; Flannery and Rangan 2008). It can therefore be seen as a suitable measure for the actual economic risk of a bank portfolio.

We infer a bank's asset volatility by using the market value of equity and its volatility, analogously to Ronn and Verma (1986), Flannery (2014), and others. Based on the Black–Scholes–Merton pricing framework, a bank's equity can be valued as a call option on firm assets:

$$E_{i,t} = V_{i,t}N\left(d_{i,t}\right) - D_{i,t}N\left(d_{i,t} - \sigma_{V_{i,t}}\sqrt{T}\right), \tag{2}$$

$$d_{i,t} = \frac{\ln\frac{V_{i,t}}{D_{i,t}} + 0.5\sigma^2_{V_{i,t}}T}{\sigma_{V_{i,t}}\sqrt{T}}, \tag{3}$$

$$\sigma_{V_{i,t}} = \frac{\sigma_{E_{i,t}}E_{i,t}}{V_{i,t}N(d_{i,t})}, \tag{4}$$

where $E_{i,t}$ is the market value of equity of bank i at time t, $V_{i,t}$ the market value of assets, $D_{i,t}$ the book value of total liabilities, $\sigma_{V_{i,t}}$ is the asset volatility (the annualized standard deviation of continuous asset returns), $\sigma_{E_{i,t}}$ the equity volatility, and $N()$ is the cumulative normal distribution function.[3] For a given liability maturity T, the system of nonlinear equations (2) and (4) can be solved numerically for the asset value and the asset volatility.

3.2 A model for cross-sectional and longitudinal risk sensitivity

Given the measures for regulatory and economic risk, the risk sensitivity of a regulatory standard is defined as

$$\beta = \frac{\partial RWD_{i,t}}{\partial \sigma_{i,t}}, \tag{5}$$

where $\sigma_{i,t} = \sigma_{V_{i,t}}$ is bank i's asset portfolio risk at time t. Assuming a linear relationship with zero intercept, we have the simple equation

[3] Following Ronn and Verma (1986), we assume that the face value of the debt, $D_{i,t}$, is the present value of the default point (discounted by the risk-free rate).

$$RWD_{i,t} = \beta\, \sigma_{i,t}. \tag{6}$$

As the theoretical analysis of Sect. 5.2 shows, the adequate RWD is actually almost linearly increasing with the asset volatility, so the linear relationship seems to be reasonable. Through the business cycle, the average asset portfolio risk of banks ("market risk"), denoted by $\overline{\sigma}_t$, varies. If the capital standard was fully risk-sensitive *through the cycle*, the risk-weight density of an average bank, $\overline{RWD}_t$, would vary accordingly. That would mean

$$\frac{\overline{RWD}_t}{\overline{\sigma}_t} = \frac{\overline{RWD}_s}{\overline{\sigma}_s} \tag{7}$$

for all periods t, s, yielding

$$\overline{RWD}_t = \frac{\overline{\sigma}_t}{\overline{\sigma}_s}\, \overline{RWD}_s. \tag{8}$$

If, at the other extreme, the standard was fully insensitive through the cycle,

$$\overline{RWD}_t = \overline{RWD}_s \tag{9}$$

would hold for all periods t, s.[4]

By comparing the fully cyclical standard (8) and the fully insensitive standard (9), we can qualify a standard which is in between these extreme cases by a parameter α that measures the degree to which the standard is insensitive with respect to the business cycle:[5]

$$\begin{aligned}\overline{RWD}_t &= \alpha\overline{RWD}_s + (1-\alpha)\frac{\overline{\sigma}_t}{\overline{\sigma}_s}\, \overline{RWD}_s \\ &= \left[\alpha + (1-\alpha)\frac{\overline{\sigma}_t}{\overline{\sigma}_s}\right]\overline{RWD}_s.\end{aligned} \tag{10}$$

If $\alpha = 1$, average risk weights $\overline{RWD}_t = \overline{RWD}_s$ are constant, i.e., insensitive to the business cycle (e.g., Basel I with fixed risk weights). For $\alpha = 0$, average risk weights $\overline{RWD}_t = (\overline{\sigma}_t/\overline{\sigma}_s)\overline{RWD}_s$ are fully sensitive to the business cycle by changing proportionally with average market risk. The actual capital standard resides somewhere between these two extremes. For example, under the IRB Approach for credit risk, the rating philosophy may follow either a "point-in-time" or a "through-the-cycle" approach. While point-in-time ratings represent an assessment of the borrower over a relatively short horizon, the through-the-cycle approach focuses on a longer horizon, abstracting from current cyclical conditions. Through-the-cycle ratings are therefore less cyclical than point-in-time ratings.

[4] Note that this approach implicitly assumes that the average risk-taking over all banks is constant. Hence, changes in the average risk $\overline{\sigma}_t$ are attributed to changes in the exogenous riskiness of the banking business ("market risk") and not to changes in the risk-taking behavior of banks.

[5] See Gordy and Howells (2006) for a similar idea of "counter-cyclical indexing".

To distinguish between risk sensitivity through the cycle and risk sensitivity *in the cross section* for a given point in time, we allow for time-varying β and define β_t as the cross-sectional risk sensitivity in period t:

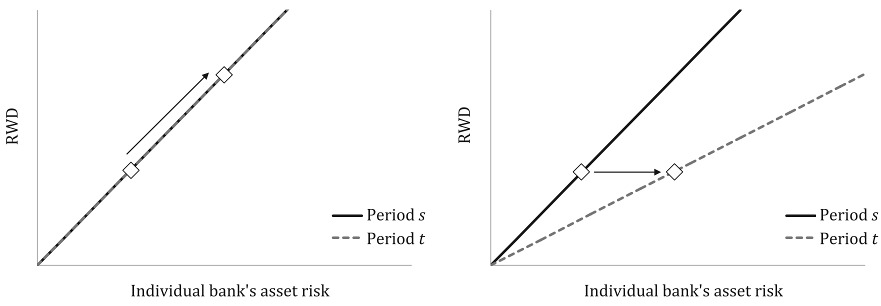
$$RWD_{i,t} = \beta_t \, \sigma_{i,t}. \tag{11}$$

Using (11) for the average bank at time t and time s and substituting into (10) yields a relation between cross-sectional risk sensitivities in different periods:

$$\begin{aligned} \beta_t \, \overline{\sigma}_t &= \left[\alpha + (1-\alpha)\frac{\overline{\sigma}_t}{\overline{\sigma}_s}\right] \beta_s \, \overline{\sigma}_s \\ \Rightarrow \beta_t &= \left[\alpha + (1-\alpha)\frac{\overline{\sigma}_t}{\overline{\sigma}_s}\right] \frac{\overline{\sigma}_s}{\overline{\sigma}_t} \, \beta_s \\ &= \left[1 + \alpha\left(\frac{\overline{\sigma}_s}{\overline{\sigma}_t} - 1\right)\right] \beta_s. \end{aligned} \tag{12}$$

For the two extreme values of α, Fig. 1 demonstrates the effect of an increase in average market risk on risk weights. The figure illustrates the risk-weight density with respect to individual bank risk, that is, the cross-sectional risk sensitivity.

For $\alpha = 0$ (Fig. 1a), risk weights move along a single risk curve and change proportionally with movements in the business cycle. The capital standard is fully sensitive to changes in an individual bank's asset risk through the cycle. That is, the standard is fully cyclical. For $\alpha = 1$ (Fig. 1b), the capital standard is completely insensitive to the business cycle. Consider a bank with a constant portfolio over time. If average market risk increases through the business cycle, the actual bank portfolio risk increases, although the business remains unchanged. For an insensitive capital standard, risk weights for such a bank do not change but move parallel to the x-axis to a different (flatter) point-in-time risk curve.



(a) $\alpha = 0$ **(b)** $\alpha = 1$

Fig. 1 Risk-weight density (RWD) with respect to bank portfolio risk. The figure shows the impact of a 100 % increase in market risk from period s to period t on RWD for a fully cyclical standard ($\alpha = 0$, *left graph*) and a fully insensitive standard ($\alpha = 1$, *right graph*). With $\alpha = 0$, RWD increases proportionally with bank portfolio risk on the constant risk curve. With $\alpha = 1$, RWD remains constant despite the increased portfolio risk, leading to a new, flattened risk curve

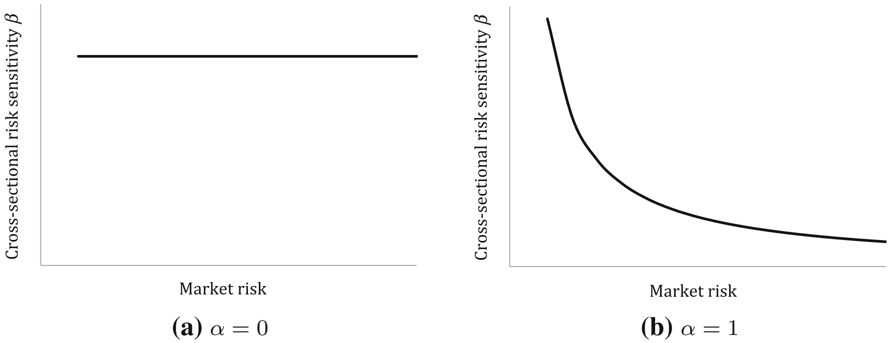


Fig. 2 Cross-sectional risk sensitivity with respect to market risk. For a fully cyclical standard ($\alpha = 0$, *left graph*), there is only one constant risk curve independent of the market risk (see Fig. 1a) and thus a constant cross-sectional risk sensitivity. For a fully insensitive standard ($\alpha = 1$, *right graph*), the slope of the risk curve (see Fig. 1b), and thus the cross-sectional risk sensitivity, decreases with increasing market risk

Figure 2 demonstrates the corresponding behavior of the cross-sectional risk sensitivity, β_t. For a fully cyclical standard ($\alpha = 0$), there is only a single risk curve (see Fig. 1a), that is, cross-sectional risk sensitivity β_t is constant through the cycle (Fig. 2a). For a standard that is fully insensitive to changes through the business cycle ($\alpha = 1$), the slope of the risk curve flattens with higher average market risk. Hence, cross-sectional risk sensitivity declines and shows a pattern as displayed in Fig. 2b.

3.3 Model estimation

As a benchmark (Model 1), we calculate unconditional risk sensitivity according to Eq. (6), analogously to Vallascas and Hagendorff (2013). For this, we regress the risk-weight density, $RWD_{i,t}$, on the volatility of bank assets, $\sigma_{i,t}$, and a set of control variables, $\theta_{i,t}$:

$$M1: \qquad RWD_{i,t} = c + \beta\sigma_{i,t} + \delta'\theta_{i,t} + \epsilon_{i,t}, \tag{13}$$

where β captures the risk sensitivity to our market measure of portfolio risk.

As discussed, β is an average measure across all sample periods capturing both cross-sectional and longitudinal risk sensitivity. If the capital standard is not fully cyclical ($\alpha > 0$), β is a flawed measure of cross-sectional risk sensitivity. Therefore, Model 2 allows for time-varying cross-sectional risk sensitivity during the business cycle by estimating different risk sensitivity coefficients β_t for each period t:

$$M2: \qquad RWD_{i,t} = c + \beta_t\sigma_{i,t} + \delta'\theta_{i,t} + \epsilon_{i,t}. \tag{14}$$

If risk weights are not completely cyclical, β_t should be lower in times of high market volatility and vice versa (see Fig. 2b).

Turning to our integrated approach and explicitly addressing the issue of cyclicality, Model 3 considers the longitudinal sensitivity by employing Eq. (12).

For the different time periods t and s, it is straightforward to use subsequent periods, that is, t and $t-1$. Substituting (12) for β_t in (14) yields:[6]

$$M3: \qquad RWD_{i,t} = c + \left[1 + \alpha\left(\frac{\overline{\sigma}_{t-1}}{\overline{\sigma}_t} - 1\right)\right]\beta_{t-1}\sigma_{i,t} + \delta'\theta_{i,t} + \epsilon_{i,t}. \tag{15}$$

Model 3 is our core model that allows us to simultaneously estimate time-varying cross-sectional risk sensitivities β_t and cyclicality α. The risk sensitivity for period t, β_t, is estimated via the pre-period sensitivity, β_{t-1}, adjusted for the variability of β through the periods. This variability adjustment is determined by the cyclicality coefficient α: For a fully cyclical standard ($\alpha = 0$), the adjustment factor equals 1, which means $\beta_t = \beta_{t-1}$. For a less cyclical standard ($\alpha > 0$), the adjustment increases β_t with respect to β_{t-1} when the average market risk has decreased and vice versa.

To analyze the impact of regulation characteristics on α, in Model 4 we allow α to interact with specific parameters Γ:

$$\alpha_{i,t} = \alpha + \xi'\Gamma_{i,t}, \tag{16}$$

Particularly, we interact α with dummies for the introduction of the Basel II Standardized and IRB Approach for credit risk. While Basel II is generally more risk sensitive, there should also be a difference between the Standardized Approach and the IRB Approach. Since external ratings are typically viewed as less sensitive to cyclic changes than internal ratings, the RWA of banks applying the Standardized Approach are likely to be less cyclical than the RWA under the IRB Approach. Hence, we expect α to be lower for Basel II banks and, in particular, for IRB banks. Model 4 reads:

$$M4: \qquad RWD_{i,t} = c + \left[1 + (\alpha + \xi'\Gamma_{i,t})\left(\frac{\overline{\sigma}_{t-1}}{\overline{\sigma}_t} - 1\right)\right]\beta_{t-1}\sigma_{i,t} + \delta'\theta_{i,t} + \epsilon_{i,t}. \tag{17}$$

As control variables, $\theta_{i,t}$, we include several bank and country characteristics. Variables comprise bank size measured as the logarithm of the total assets (in thousands of US dollars), Tier 1 capital ratio, and bank profitability via return on assets, ROA (defined as net income over total assets). Additionally, we control for income diversity (share of non-interest income over total operating income) and for the bank's asset structure by the ratio of deposits to total assets and the ratio of net loans to total assets. We further control for the accounting standard. While U.S. banks report in accordance with US GAAP, most other jurisdictions require the use of IFRS for our sample banks. One of the key differences between IFRS and US GAAP are the offsetting requirements. This usually results in IFRS balance sheets for banks appearing to be larger and hence, RWD appearing lower, all else being equal (Le Leslé and Avramova 2012). We therefore include a dummy variable,

[6] Note that we derived (12) under the assumption of a zero intercept, while we allow for a non-zero intercept in the empirical assessment. However, in contrast to the relation of risk weights (11), the crucial relation (12) also holds in this setting, as we still have $\beta_t = \beta_s$ for a fully cyclical standard and $\beta_t = \frac{\overline{\sigma}_s}{\overline{\sigma}_t}\beta_s$ for a fully insensitive standard.

USGAAP, that equals one if a bank reports under US GAAP. Finally, we include dummy variables for Basel II adoption, where SA and IRB are set to one from the year a bank reports RWA under the Standardized Approach and the IRB Approach, respectively.

To derive a bank's asset volatility via (4), we collect daily stock returns from Datastream. Equity volatility, $\sigma_{E_{i,t}}$, is measured as the annualized standard deviation of the daily stock returns over the year's final quarter. The market value of equity, $E_{i,t}$, is measured on the year's last trading day, and D_t is obtained as total debt from the year's balance sheet. Following Ronn and Verma (1986) and others, we set $T = 1$ and then compute $V_{i,t}$ and $\sigma_{V_{i,t}}$ at each year-end. We calculate average market risk, $\overline{\sigma}_t$, by the mean of the sample's individual bank asset volatilities, weighted by banks' total assets. We compute global market risk as well as regional market risks for five regions, i.e., Europe, North America, South America, Asia, and Australia.

Models 1 and 2 are estimated by ordinary least squares. For Model 3 we estimate the system of (non-linear) equations (14) and (15) by employing nonlinear least-squares, for Model 4 analogously with (14) and (17). Throughout the paper we report robust standard errors for clustering at the bank level.

Table 1 Descriptive statistics of the data sample

	N	Mean	Median	SD	1 Pctile	99 Pctile
RWD	2058	0.588	0.579	0.183	0.184	0.994
RWDGC	1967	0.744	0.740	0.266	0.213	1.599
Asset volatility	2058	0.031	0.022	0.032	0.004	0.176
Size	2058	18.080	17.798	1.650	15.114	21.635
Tier 1	2058	0.109	0.104	0.038	0.058	0.242
Net loans	2058	0.621	0.645	0.153	0.159	0.907
Deposits	2058	0.620	0.648	0.202	0.115	0.932
Income diversity	2058	0.292	0.280	0.141	0.031	0.720
ROA	2058	0.006	0.006	0.008	−0.021	0.021
USGAAP	2058	0.32	0.00	0.47	0.00	1.00
SA	2058	0.16	0.00	0.37	0.00	1.00
IRB	2058	0.24	0.00	0.43	0.00	1.00

The sample covers annual observations for 200 banks and 28 OECD countries over the period 2001–2014. RWD is the ratio of risk-weighted assets (RWA) to total assets. RWDGC is the global charge measure and equals the sum of RWA and loan loss provisions, scaled by total assets. Asset volatility is the market assessment of bank portfolio risk estimated via option pricing theory. Size is the logarithm of total assets (in thousands of US dollars). Tier 1 is the Tier 1 capital ratio, defined as Tier 1 capital (common stocks plus perpetual, non-cumulative preferred stocks plus retained earnings) to RWA. Net Loans and Deposits are as reported in Worldscope and scaled by total assets. Income diversity is the share of non-interest income over total operating income. ROA is net income over total assets. USGAAP is a dummy which is set to one if a bank reports under US GAAP. SA and IRB are dummy variables that equal one if a bank reports RWA under the Standardized Approach for credit risk or the IRB Approach for credit risk, respectively

The regression models may suffer from potential endogeneity of the asset volatility, which may in part be determined by the regulatory assessment of portfolio risk embodied in the RWD (Vallascas and Hagendorff 2013). We therefore conduct an instrumental regression using the volatility of the MSCI World Index as an instrument for the asset volatility. The instrument highly correlates with asset volatility (correlation 0.51), but not with RWD (correlation 0.01). However, employing a Durbin-Wu-Hausman test (see Davidson and MacKinnon 1993), we are not able to reject the null hypothesis of exogeneity. We can thus be confident that the potential endogeneity problem is not severe and run the regressions without instrumental variables.

3.4 Sample

We analyze a sample of 200 large banks from 28 OECD countries. The banks were selected according to size (US dollar total assets) from Datastream. We omit banks that are subsidiaries of other banking firms and require that sample banks have at least five years of accounting data on the Thomson Reuters Worldscope database. Information on Basel II introduction and IRB approval dates was hand-collected from the banks' Pillar 3 reports and annual reports. The panel is unbalanced and covers the years 2001–2014. Table 1 presents descriptive statistics of the variables employed in the empirical analysis.

The sample distribution by year and the evolution of Basel II adoption is presented in Table 2, where our definition of Basel II adoption refers to reporting of RWA under the Basel II regime. Basel II adoption started with 2007 and jumped to 61 % in 2008. Since the majority of U.S. banks still report under Basel I until 2014, the adoption rate in 2014 is only at 67.5 %.

Table 2 Sample distribution by year and Basel II adoption

	N (%)	Basel II adoption (%)		
		SA	IRB	Total
2001	62 (3.0)	0.0	0.0	0.0
2002	69 (3.4)	0.0	0.0	0.0
2003	87 (4.2)	0.0	0.0	0.0
2004	136 (6.6)	0.0	0.0	0.0
2005	156 (7.6)	0.0	0.0	0.0
2006	169 (8.2)	0.0	0.0	0.0
2007	176 (8.6)	9.5	11.0	20.5
2008	174 (8.5)	27.5	33.5	61.0
2009	176 (8.6)	28.0	35.5	63.5
2010	188 (9.1)	26.0	37.5	63.5
2011	189 (9.2)	26.0	37.5	63.5
2012	185 (9.0)	26.5	39.0	65.5
2013	152 (7.4)	26.5	41.0	67.5
2014	139 (6.8)	28.5	41.0	67.5

Basel II adoption refers to reporting of RWA under the Standardized Approach (SA) or the IRB Approach for credit risk. Adoption is expressed as percentage of total banks in the sample

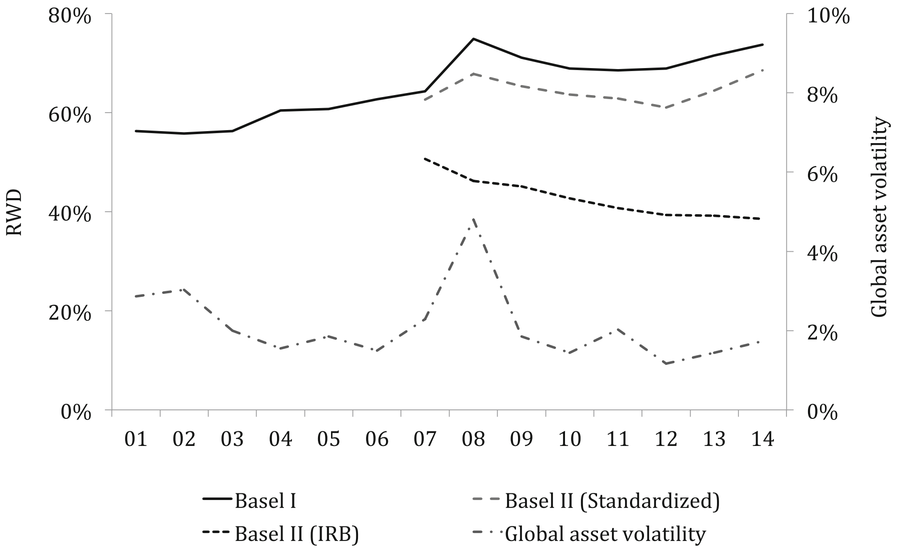


Fig. 3 Evolution of the average risk-weight density (RWD, *left scale*) and global asset volatility (*right scale*). RWD is differentiated between Basel I banks and banks using the Basel II Standardized and IRB Approach. Banks with less than 10 yearly observations are excluded. Global asset volatility is calculated as weighted average of banks' asset volatilities

Figure 3 shows the evolution of RWD over time, differentiating between Basel I, Basel II Standardized Approach and IRB Approach banks.[7] The figure also displays the average global asset volatility. The development of RWD after the introduction of Basel II in 2007 differs substantially: while average RWD for banks employing the Standardized Approach is around 65 %, RWD for IRB banks decreased continuously from 51 % in 2007 to 38 % in 2014.[8] This is remarkable, especially considering the dramatic increase in global asset volatility during the financial crisis in 2007/2008. The graph suggests that the risk weights of IRB banks were on average not affected by the rise in market risk. We consider this to be a first indication that cyclicality of risk weights is low, even under Basel II.

4 Empirical results

4.1 Risk sensitivity of the regulatory standard

Table 3 shows the model estimation results, including the beta coefficients and hence the cross-sectional risk sensitivity as well as the alpha coefficient with its interaction terms, referring to cyclicality, and the control variables. (Note that for

[7] We exclude banks with less than 10 yearly observations.

[8] Blundell-Wignall and Roulet (2013) and Mariathasan and Merrouche (2014) present similar RWD developments for different samples.

Table 3 Regression results on risk-weight density (RWD), according to Models 1–4

	Model 1	Model 2	Model 3	Model 4
Constant	0.342*** (0.125)	0.342*** (0.127)	0.342*** (0.128)	0.342*** (0.128)
β	0.454*** (0.123)			
β_{2001}		1.159** (0.574)	0.921** (0.458)	0.938** (0.457)
β_{2002}		0.660* (0.343)	0.663*** (0.256)	0.686*** (0.262)
β_{2003}		0.995** (0.483)	0.987*** (0.360)	1.021*** (0.362)
β_{2004}		1.209*** (0.445)	1.092*** (0.410)	1.123*** (0.411)
β_{2005}		0.916** (0.402)	0.925** (0.363)	0.976*** (0.360)
β_{2006}		1.111*** (0.398)	1.268*** (0.375)	1.273*** (0.374)
β_{2007}		0.963*** (0.259)	0.887*** (0.241)	0.871*** (0.240)
β_{2008}		0.334*** (0.111)	0.362*** (0.108)	0.374*** (0.107)
β_{2009}		1.396*** (0.357)	1.245*** (0.321)	1.265*** (0.321)
β_{2010}		1.295*** (0.411)	1.357*** (0.345)	1.403*** (0.365)
β_{2011}		1.095*** (0.230)	1.115*** (0.253)	1.121*** (0.253)
β_{2012}		2.112*** (0.602)	2.109*** (0.581)	2.200*** (0.585)
β_{2013}		1.994*** (0.632)	1.942*** (0.615)	2.028*** (0.607)
β_{2014}		1.658** (0.678)	1.652** (0.682)	1.668** (0.683)
Alpha			0.915***	0.852***
1−Alpha			0.085 (0.104)	0.148* (0.105)
Alpha × SA				−0.241 (0.463)
Alpha × IRB				0.621*** (0.193)
Size	−0.006 (0.005)	−0.006 (0.005)	−0.006 (0.005)	−0.005 (0.005)
Tier 1	−1.358*** (0.175)	−1.484*** (0.179)	−1.485*** (0.175)	−1.488*** (0.175)
Net loans	0.624*** (0.050)	0.615*** (0.051)	0.615*** (0.050)	0.615*** (0.050)
Deposits	−0.011 (0.042)	−0.014 (0.041)	−0.016 (0.041)	−0.016 (0.041)
Income diversity	0.176*** (0.058)	0.172*** (0.058)	0.171*** (0.057)	0.170*** (0.058)
ROA	1.987*** (0.572)	1.772*** (0.511)	1.763*** (0.514)	1.749*** (0.512)
USGAAP	0.194*** (0.018)	0.184*** (0.019)	0.183*** (0.019)	0.183*** (0.019)
SA	−0.001 (0.016)	−0.002 (0.015)	−0.003 (0.015)	−0.003 (0.015)
IRB	−0.054*** (0.014)	−0.054*** (0.014)	−0.055*** (0.014)	−0.055*** (0.014)
Observations	2058	2058	2058	2058
R-squared	0.643	0.652	0.652	0.652

The β coefficients capture the cross-sectional risk sensitivity per year. Alpha is the measure for the longitudinal sensitivity of risk weights, where a value of one represents an insensitive standard. SA and IRB are dummies that equal one if a bank adopts the Standardized Approach or the IRB Approach to compute RWA, respectively. Size is the logarithm of total assets (in thousands of US dollars). Tier 1 is the Tier 1 capital ratio, defined as Tier 1 capital (common stocks plus perpetual, non-cumulative preferred stocks plus retained earnings) to RWA. Net Loans and Deposits are as reported in Worldscope and scaled by total assets. Income Diversity is the share of non-interest income over total operating income. ROA is net income over total assets. USGAAP is a dummy which is set to one if a bank reports under US GAAP. Robust standard errors (in parentheses) are clustered at the bank level. Significance is indicated at the 10 % level as *, at the 5 % level as **, and at the 1 % level as ***

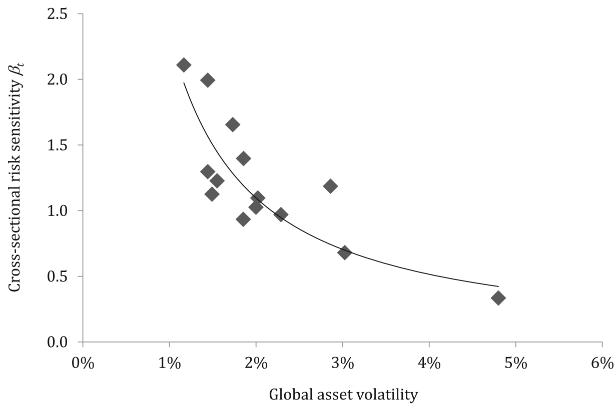


Fig. 4 The figure shows yearly estimates of cross-sectional risk sensitivity, β_t, according to Eq. (14) with respect to global asset volatility. The *solid line* represents a fitted exponential function (power of −1.1)

Model 1, the beta coefficient refers to both cross-sectional and longitudinal risk sensitivity.)

With Model 1, the unconditional risk sensitivity amounts to 0.454, which confirms the results of Vallascas and Hagendorff (2013), who report coefficients of 0.427–0.473 with several model specifications.[9] This means that an increase in asset volatility of 1 % point leads to an average increase in RWD of only 0.454 % points.

However, if we consider potential changes in risk sensitivity through the cycle, we get a different picture. Model 2 estimates the cross-sectional risk sensitivity separately for each year. Risk sensitivity varies significantly between 0.334 (2008) and 2.112 (2012). Except for 2008, yearly sensitivities are larger than the average in Model 1 (0.454). Thus, the unconditional beta coefficient is indeed a flawed measure for cross-sectional risk sensitivity.

The risk sensitivity is particularly low during the financial crisis, while it is large in times of lower average market volatility. Figure 4 displays the dependence of yearly cross-sectional risk sensitivity on the corresponding global asset volatility. The association between risk sensitivity and market risk is consistent with a regulatory standard that is relatively insensitive with respect to the business cycle, as shown in Fig. 2a. If average risk weights do not change through the cycle, risk sensitivity becomes lower when market risk is larger.

Model 3 introduces the parameter α that classifies the standard between a fully cyclical approach ($\alpha = 0$) and a fully insensitive approach ($\alpha = 1$). The estimated value of $\alpha = 0.915$ with a standard error of 0.104 confirms the previous indications that the standard is very close to an insensitive approach.

However, the estimate of α represents an average, since our sample period covers both Basel I and Basel II observations. Furthermore, Basel II banks differ in the chosen approach for credit risk (Standardized vs. IRB Approach). In Model 4, we

[9] This coincidence is a further indication that there is no severe endogeneity problem with our model, as Vallascas and Hagendorff (2013) come to very similar results by means of an instrumental variables regression.

therefore introduce interactions between α and the dummy variables for the Basel II Standardized and IRB Approach. The use of the Standardized Approach lowers the value of α, which means that the standard becomes more cyclical. However, the interaction coefficient is not significant. In contrast, the use of the IRB Approach increases the value of α, which indicates an even less cyclical standard. The opposite would have been expected, as the IRB Approach is supposed to increase cyclicality (see, among many others, Kashyap and Stein 2004). A possible reason might be that banks adopting the IRB Approach tend to delay necessary adjustments in their internal ratings in phases of market downturn. Indeed, recent studies have found indications that banks tend to manipulate their RWA and hence their rating systems in order to keep regulatory capital requirements low (Mariathasan and Merrouche 2014). Although the IRB interaction effect is highly significant, it should not be overrated as significance disappears in the robustness analysis in the next section.

In terms of the control variables, RWD decreases with IRB implementation (significant at the 1 % level). On average, IRB banks exhibit a risk-weight density that is about 5 % points lower. On the other hand, introduction of the Standardized Approach does not influence RWD. As expected, RWD is significantly higher for banks reporting under US GAAP. Furthermore, RWD increases in loans and ROA (both significant at 1 %). Hence, banks' lending activities are associated with higher risk weights. Regarding the association with ROA, Vallascas and Hagendorff (2013) argue that higher profitability reduces a bank's incentives to engage in capital arbitrage by reporting lower values of RWD. However, the negative relation might also result from the fact that RWA for credit risk are based on unexpected losses. If banks anticipate expected losses through loan loss provisions, ROA will be negatively affected, and simultaneously—since RWA are calculated net of expected losses—RWD will also tend to decrease. We tackle this issue in the robustness section by considering an alternative measure for regulatory risk assessment that accounts for expected losses. Finally, the Tier 1 ratio is negatively related to RWD (significant at the 1 % level). Hence, banks with higher capital ratios exhibit lower regulatory risk exposure.

4.2 Robustness analyses

We perform additional tests on Model 4 to examine whether the results are robust to changes in our measure of regulatory risk, the estimation of longitudinal sensitivity, or the composition of the sample.

First, we consider an adjusted measure for the dependent variable. As mentioned, RWA for credit exposures are based on unexpected losses, where the breakdown of total risk into expected and unexpected losses may vary across banks depending on the type of business and the regulatory approach (i.e., Standardized versus IRB). As Arroyo et al. (2012) point out, this may lead to differences in RWD that do not necessarily reflect differences in risk. They propose a modified measure, "global charge", which includes the expected loss, EL, in the numerator:

$$RWDGC_{i,t} = \frac{RWA_{i,t} + 12.5EL_{i,t}}{TA_{i,t}}. \quad (18)$$

This ratio is also applied by the European Banking Authority in its 2013 assessment of RWA consistency (European Banking Authority 2013a). In line with Mariathasan and Merrouche (2014) we proxy (unobservable) expected losses by loan loss provisions.

Second, we consider the relation between changes in RWD and market risk for a longer time horizon and estimate Model 4 with a time lag of two periods ("Lag 2"):

$$RWD_{i,t} = c + \left[1 + (\alpha + \xi'\Gamma_{i,t})\left(\frac{\overline{\sigma}_{t-2}}{\overline{\sigma}_t} - 1\right)\right]\beta_{t-2}\sigma_{i,t} + \delta'\theta_{i,t} + \epsilon_{i,t}. \quad (19)$$

Third, temporal changes in the cross-sectional risk sensitivity might not only be driven by changes in market risk through the business cycle. Amendments to the regulatory framework, particularly the introduction of Basel II, may also affect risk sensitivity. We therefore introduce additional interaction terms between asset volatility and the Basel II dummies, SA and IRB. Analogous to the alpha interaction, the modified model with beta interaction reads:

$$RWD_{i,t} = c + \left[1 + (\alpha + \xi'\Gamma_{i,t})\left(\frac{\overline{\sigma}_{t-1}}{\overline{\sigma}_t} - 1\right)\right](\beta_{t-1} + \gamma'\Gamma_{i,t})\sigma_{i,t} + \delta'\theta_{i,t} + \epsilon_t. \quad (20)$$

Fourth and finally, we split our sample into three sub-periods: a pre-crisis period 2001–2005, a period from 2006–2010 that covers the financial crisis, and a post-crisis period 2011–2014.

In the second column, global charge is used as the dependent variable. Lag 2 refers to a time lag of two periods for the relation between changes in RWD and market asset risk (see Eq. 19). Beta Interact in the fourth column describes the inclusion of interaction effects between asset volatility and Basel II dummies (see Eq. 20). The final three columns show sample subperiods. The β coefficients capture the cross-sectional risk sensitivity per year. Alpha is the measure for the longitudinal sensitivity of risk weights, where a value of one refers to an insensitive standard. SA and IRB are dummies that equal one if a bank adopts the Standardized Approach or the IRB Approach to compute RWA, respectively. Size is the logarithm of total assets (in thousands of US dollars). Tier 1 is the Tier 1 capital ratio, defined as Tier 1 capital (common stocks plus perpetual, non-cumulative preferred stocks plus retained earnings) to RWA. Net Loans and Deposits are as reported in Worldscope and scaled by total assets. Income Diversity is the share of non-interest income over total operating income. ROA is net income over total assets. USGAAP is a dummy which is set to one if a bank reports under US GAAP. Robust standard errors (in parentheses) are clustered at the bank level. Significance is indicated at the 10 % level as *, at the 5 % level as **, and at the 1 % level as ***

Table 4 shows the results of the robustness analyses. Overall, the results confirm our assessment that the regulatory standard is rather insensitive with respect to the business cycle: We obtain similar values for α in all model specifications. The standard is almost insensitive, yet α is somehow smaller than one with significance

Table 4 Results of the robustness checks, based on Model 4

	Global charge	Lag 2	Beta interact	2001–2005	2006–2010	2011–2014
Constant	0.467* (0.280)	0.340*** (0.127)	0.338*** (0.128)	0.312* (0.184)	0.385** (0.155)	0.349** (0.150)
β_{2001}	2.954*** (0.708)	1.121** (0.532)	1.002** (0.457)	1.523*** (0.494)		
β_{2002}	2.109*** (0.536)	0.672** (0.308)	0.747*** (0.272)	0.885** (0.371)		
β_{2003}	3.428*** (0.689)	0.963** (0.405)	1.118*** (0.381)	1.025* (0.552)		
β_{2004}	3.636*** (0.790)	1.248*** (0.434)	1.230*** (0.433)	1.131* (0.687)		
β_{2005}	2.981*** (0.664)	0.982** (0.389)	1.078*** (0.381)	0.798 (0.645)		
β_{2006}	3.406*** (0.704)	1.157*** (0.398)	1.369*** (0.389)		0.642 (0.475)	
β_{2007}	1.773*** (0.428)	0.999*** (0.253)	0.923*** (0.246)		0.518* (0.282)	
β_{2008}	0.847*** (0.173)	0.346*** (0.110)	0.428*** (0.124)		0.215* (0.119)	
β_{2009}	3.485*** (0.663)	1.374*** (0.336)	1.351*** (0.343)		0.720** (0.362)	
β_{2010}	4.369*** (0.901)	1.336*** (0.412)	1.496*** (0.410)		0.774* (0.433)	
β_{2011}	3.824*** (0.436)	1.117*** (0.240)	1.282*** (0.298)			1.146*** (0.336)
β_{2012}	7.265*** (1.104)	2.153*** (0.602)	2.317*** (0.613)			2.288*** (0.745)
β_{2013}	7.266*** (0.957)	2.025*** (0.634)	2.174*** (0.589)			2.085*** (0.804)
β_{2014}	6.712*** (0.905)	1.675** (0.686)	1.877*** (0.603)			1.742** (0.808)
Alpha	0.875***	0.853***	0.827***	0.803**	0.905***	0.616***
1−Alpha	0.125* (0.081)	0.147* (0.097)	0.173* (0.101)	0.197 (0.355)	0.095 (0.209)	0.384** (0.233)
Alpha × SA	−0.483* (0.274)	0.140 (0.382)	−0.184 (0.416)		0.370 (1.121)	−0.175 (0.485)
Alpha × IRB	0.050 (0.237)	0.159 (0.282)	0.588** (0.276)		0.276 (0.579)	0.890*** (0.255)
Beta × SA			0.194 (0.593)			
Beta × IRB			−0.390 (0.309)			
Size	−0.010 (0.011)	−0.006 (0.005)	−0.005 (0.005)	−0.008 (0.007)	−0.008 (0.006)	0.004 (0.006)
Tier 1	−1.640*** (0.430)	−1.487*** (0.176)	−1.503*** (0.177)	−1.396*** (0.337)	−1.484*** (0.254)	−1.535*** (0.201)

Table 4 continued

	Global charge	Lag 2	Beta interact	2001–2005	2006–2010	2011–2014
Net loans	0.827*** (0.096)	0.616*** (0.050)	0.616*** (0.051)	0.569*** (0.075)	0.634*** (0.058)	0.574*** (0.061)
Deposits	−0.075 (0.065)	−0.015 (0.041)	−0.014 (0.041)	0.075 (0.046)	0.008 (0.051)	−0.076 (0.049)
Income diversity	0.237*** (0.091)	0.173*** (0.058)	0.168*** (0.058)	0.204** (0.081)	0.229*** (0.067)	0.094 (0.068)
ROA	−5.250*** (1.137)	1.732*** (0.507)	1.724*** (0.522)	6.739*** (2.055)	1.223 (0.882)	1.520** (0.614)
USGAAP	0.129*** (0.030)	0.183*** (0.019)	0.181*** (0.019)	0.148*** (0.032)	0.173*** (0.025)	0.115*** (0.032)
SA	0.014 (0.034)	−0.003 (0.015)	−0.007 (0.018)		−0.046** (0.022)	−0.060*(0.032)
IRB	−0.015 (0.029)	−0.054*** (0.014)	−0.046*** (0.015)		−0.060*** (0.019)	−0.165*** (0.036)
Observations	1967	2058	2058	510	883	665
R-squared	0.436	0.652	0.652	0.651	0.641	0.699

In the second column, global charge is used as the dependent variable. Lag 2 refers to a time lag of two periods for the relation between changes in RWD and market asset risk (see Eq. 19). Beta Interact in the fourth column describes the inclusion of interaction effects between asset volatility and Basel II dummies (see Eq. 20). The final three columns show sample subperiods. The β coefficients capture the cross-sectional risk sensitivity per year. Alpha is the measure for the longitudinal sensitivity of risk weights, where a value of one refers to an insensitive standard. SA and IRB are dummies that equal one if a bank adopts the Standardized Approach or the IRB Approach to compute RWA, respectively. Size is the logarithm of total assets (in thousands of US dollars). Tier 1 is the Tier 1 capital ratio, defined as Tier 1 capital (common stocks plus perpetual, non-cumulative preferred stocks plus retained earnings) to RWA. Net Loans and Deposits are as reported in Worldscope and scaled by total assets. Income Diversity is the share of non-interest income over total operating income. ROA is net income over total assets. USGAAP is a dummy which is set to one if a bank reports under US GAAP. Robust standard errors (in parentheses) are clustered at the bank level. Significance is indicated at the 10 % level as *, at the 5 % level as **, and at the 1 % level as ***

at a low level. As mentioned, the robustness tests do not support the proposition that the IRB Approach is less cyclical than Basel I. For both Global Charge and Lag 2 regressions, the interaction between alpha and IRB is not significantly different from zero. Furthermore, both coefficients on the beta interaction are insignificant. Hence, we find no indication that the implementation of Basel II has increased cross-sectional risk sensitivity. We conclude that the current regulatory standard is fairly insensitive to the business cycle and that Basel II has neither increased cyclicality nor cross-sectional risk sensitivity.

Notably, for the global charge regression, the risk sensitivity to the alternative economic risk measure is considerably stronger. Further, contrary to the results of the previous section, RWD decreases in ROA (significant at the 1 % level). We attribute the negative association to the fact that RWDCG includes expected losses.

If banks anticipate losses through loan loss provisions, the numerator of RWDGC increases, while ROA decreases.

5 Adequacy of risk sensitivity and capital requirements

5.1 Assessment of cross-sectional risk sensitivity

According to our differential analysis, the cross-sectional risk sensitivity depends heavily on the business cycle and is in normal times by far larger than the value of about 0.4 as reported by Vallascas and Hagendorff (2013). However, even a risk sensitivity of $\beta = 2.2$ (as found for 2012, for example) does not necessarily reflect actual bank risk to an adequate degree. In this section, we discuss the adequacy of the empirical risk sensitivity based on theoretical considerations.

Cross-sectional risk sensitivity describes the effect of changes in bank portfolio risk on RWD and thus on capital requirements. Multiplying RWD by the minimum regulatory capital ratio (8 % for Basel II) yields the associated capital requirements (per unit of total assets). Based on the regression results for Model 4, we estimate the effect of changes in asset volatility on capital requirements. Even for 2012, the year with the highest cross-sectional risk sensitivity, the impact is rather low. Other things being equal, a 1 % point increase in bank's asset volatility leads to an increase in RWD of 2.2 % points. Under the current capital standard with a 8 % solvability ratio, the change in RWD causes an increase in required capital of only 0.17 % points. For the Basel III 10.5 % solvability ratio, the impact on capital requirements still amounts to only 0.23 % points.

Figure 5 displays the cross-sectional risk sensitivity for the polar years 2008 and 2012 with the lowest and highest risk sensitivity, transferred into capital requirements (in units of total assets) based on the solvability ratio of 8 %.[10] Note that banks' actual capital may differ from the calculated capital requirements since banks may hold capital buffers above the 8 % minimum regulatory capital (the mean Tier 1 ratio for our sample is 11 %). The figure also shows the kernel density estimates for banks' asset volatility of both years.

We can make three basic observations: First, the intercept, being about 4 %, lies far from zero. Hence, even banks with very low portfolio risks are required to hold a substantial amount of capital on average. Such a requirement represents a connection to the Basel III leverage ratio, which requires banks to hold a minimum Tier 1 capital of 3 % of their total exposure, regardless of asset risk. However, the leverage ratio is not redundant, as the displayed curve is only an average over all banks, and single banks exhibit RWDs below 37.5 %, leading to risk-based capital requirements below the leverage ratio.[11] Second, even for the year 2012, the curve is rather flat. For this year, asset volatilities within our comprehensive sample range

[10] We utilize Model 2 and, to assess the level of the intercept and the slope of the curves, omit control variables.

[11] The leverage ratio is not indisputable. There is theoretical evidence that it may actually lead to higher risk-taking, see Burghof and Müller (2014).

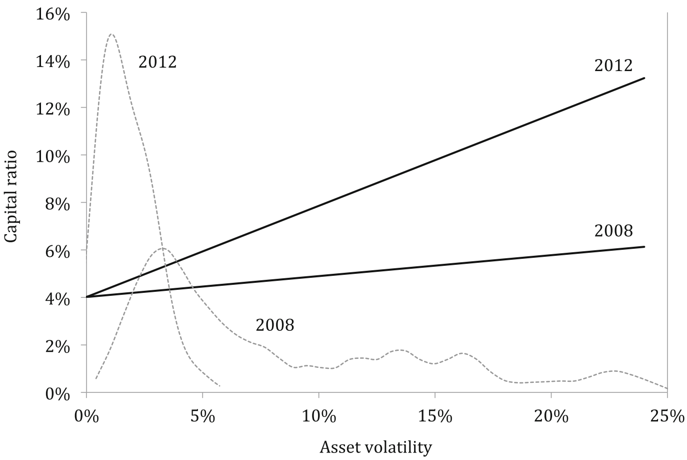


Fig. 5 The figure displays the cross-sectional risk sensitivity (*solid lines*) for the years 2008 and 2012, translated into capital requirements (in units of total assets). The capital ratio *E*/*V* is obtained by multiplying the RWD by the solvability ratio of 8 %. The RWD response to asset volatility is estimated by Model 2 (with controls omitted). *Dashed lines* represent the kernel density estimates for banks' asset volatility of both years

from 0 to 6 %. Consequently, the range of asset volatility can only explain a difference between 50 % and about 75 % in RWD, or, 4 to 6 % in minimum capital requirements. Third, as the standard is almost longitudinally insensitive and risk weights hardly respond to the business cycle, the curve is considerably flatter for the crisis year 2008. Even large values of asset volatility beyond 10 % only lead to moderately higher capital requirements.

Thus, even with a differential assessment of longitudinal and cross-sectional risk sensitivity, the latter remains quite low. This observation casts some doubt on the necessity of a highly complex RWA calculation. Why should banks and regulators expend enormous efforts in calculating and monitoring risk-based capital requirements if the output explains only a small proportion of actual bank risk? The Basel Committee has implicitly also raised this question in its 2013 consultation paper on the trinity of simplicity, comparability, and risk sensitivity of a regulatory standard (Basel Committee on Banking Supervision 2013c).

5.2 Assessment of capital requirements

To judge whether the level and slope of the risk curve is adequate, we employ a theoretical model of bank risk and bank default. The benchmark for adequacy is the statement of the Basel Committee that the minimum capital requirements should assure a bank default probability below 0.1 % (Gordy and Howells 2006).

Similar to Flannery (2014), we apply a Merton-style model to obtain a bank's (risk-neutral) probability of default, *PD*:

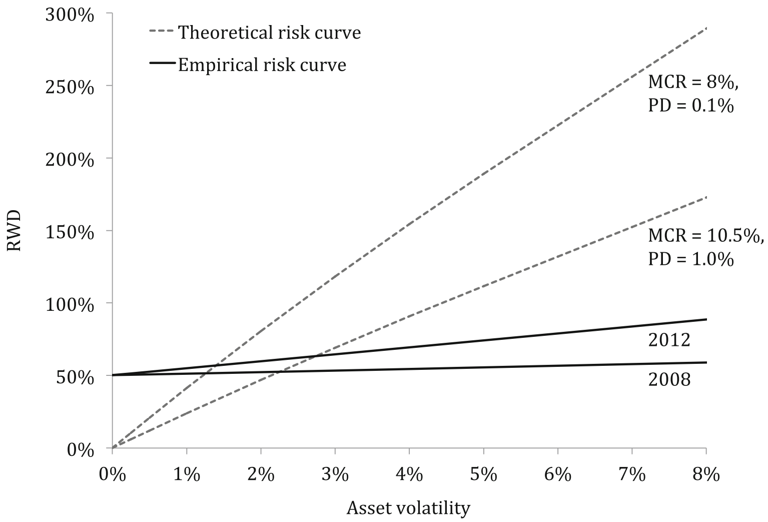


Fig. 6 The figure contrasts the empirical risk curves (*solid lines*) for the years 2008 and 2012 with theoretical risk curves (*dashed lines*). Empirical risk curves are estimated according to Model 2 (with controls omitted). Theoretical risk curves are based on Merton model default probabilities. The critical capital ratio for a (risk-neutral) default probability of 0.1 and 1.0 % are translated into RWD by dividing the ratio by the Basel minimum capital requirements of 8 and 10.5 %, respectively

$$PD_{i,t} = 1 - N\left(\frac{\ln \frac{V_{i,t}}{D_{i,t}} - 0.5\sigma^2_{V_{i,t}}T}{\sigma_{V_{i,t}}\sqrt{T}}\right). \tag{21}$$

For any given asset volatility, we are able to calculate the required capital ratio E/V (based on market values) to maintain a 1-year PD of 0.1 %. This critical capital ratio can be converted into an implicit RWD by dividing E/V by the minimum regulatory capital ratio. For example, a critical capital ratio of 4 % for a minimum regulatory ratio of 8 % implies a critical RWD of 50 %.[12] In doing so, we derive a theoretical risk curve. For a given PD, the slope of this curve is determined by the minimum capital ratio. The higher this ratio, the flatter the theoretical risk curve.

Figure 6 contrasts the theoretical risk curve to obtain a 1-year PD of 0.1 % for a minimum regulatory ratio (MCR) of 8 % with the empirical risk curves according to Sect. 5.1. An empirical risk curve beneath the theoretical curve implies a PD above the threshold.

The critical RWD (almost linearly) increases with asset volatility. Compared to the slope of the theoretical risk curve, the empirical risk sensitivity is relatively low. Further, unless for very small values of the asset volatility, the current standard is not sufficient to achieve the Basel Committee's self-established objective of retaining a default probability below 0.1 %. For the post-crisis year 2012, the goal

[12] Since RWD is defined for book values, the calculation assumes a market-to-book ratio of 1.

was achieved by only about half of the banks in our sample.[13] What is more, the low longitudinal risk sensitivity of the capital standard leads to dramatically increased default probabilities in times of high market volatility. As the cross-sectional risk curve for the crisis year 2008 is even flatter than for 2012, the majority of banks failed to comply with the maximum default probability.

However, these assessments are based on the asset volatility as an economic risk measure and the somewhat restrictive Merton model. Since the asset volatility is derived from the volatility of the bank's equity as a residual claim, it is actually not only an asset volatility. Changes in the market value of equity can, for example, also be induced by changes in the market value of liabilities. Such changes are not reflected in the regulatory risk measure. The use of this "asset" volatility is nonetheless useful also from a theoretical perspective within the regulatory context: From the regulator's point of view, the default risk of the bank should matter. Default can also be triggered by changes in the market value of liabilities, for example with foreign debt, even in the case of riskless assets. Hence, an asset volatility derived from equity volatility that also reflects liability and off-balance-sheet risk is a reasonable benchmark for regulatory purposes.

Regarding the Merton model, there are two major issues in our context: First, the model refers to market values of equity, while the regulatory standard is based on book values. Second, the model-implied default probabilities are calculated under the risk-neutral measure, not under the real-world (or physical) measure.

Regarding the first issue, we can adjust the model results by a market-to-book ratio of equity. We calculated an average market-to-book ratio of all the firms in our sample, separating the pre-crisis period (until 2007) and the crisis/post-crisis period (since and including 2008). While the average market-to-book ratio before the financial crisis took a value of 1.75, this figure has amounted to 1.01 in the years since 2008. Hence, on average, the (model-relevant) market value of equity is currently almost identical with the (regulation-relevant) book value of equity. In this regard, the model results can (at least on average) directly be transferred into the regulatory setting without adjustment.

The second issue however is severe. Risk-neutral default probabilities are substantially larger than real-world default probabilities, especially when their level is low. Based on reasonable assumptions, a desired real-world default probability of 0.1 % translates into a risk-neutral default probability of about 0.2–0.3 % (Berg 2010). Comparing actual default rates with credit spreads, Hull et al. (2005) even deduce a ratio of about 10—that is, a real-world default probability of 0.1 % is consistent with a risk-neutral default probability of 1.0 %.

Figure 6 therefore also displays a theoretical risk curve for a risk-neutral 1-year PD of 1.0 %, in combination with the stricter Basel III minimum regulatory ratio of 10.5 %. Both modifications lead to a flatter theoretical risk curve. As becomes obvious, even this generous model adjustment produces to a risk curve that is above the empirical risk curve for asset volatilities larger than about 3 %. While this might

[13] 53 % of the banks in our 2012 sample exhibit an asset volatility below 1.54 %, the intersection of the theoretical and empirical risk curves.

be sufficient in normal times, it is not in crisis periods. As Fig. 5 shows, the average bank asset volatility in 2008 was about 8 % with several values exceeding 20 %.

But it should be the goal of a regulatory standard to ensure bank stability particularly in crisis periods. Based on the assessment of risk sensitivity and minimum capital requirements, a crisis similar to that of 2007/2008 is supposed to lead to bank default rates far above the desired 0.1 %—even with the stricter Basel III capital requirements. To avoid such negative consequences, regulators could act in two ways: they could increase the risk sensitivity of the standard, which would raise the slope of the empirical risk curve. Or, they could (further) increase minimum capital requirements, which would decrease the slope of the theoretical curve. However, an increase in longitudinal risk sensitivity of the standard is not desirable, as it would lead to pro-cyclicality with all the adverse consequences. The cross-sectional risk curve in crisis periods is therefore necessarily flatter than in normal periods. Hence, to avoid oversensitive risk weights in normal times, the remaining option to achieve lower default probabilities would include a further increase of capital requirements. This judgement is in line with the call for a substantial recapitalization of banks raised by a number of authors, the most prominent being Admati et al. (2013).

Our analyses further imply that the Basel III leverage ratio with a proposed calibration of 3 % Tier 1 capital will not lead to significant improvements in capital adequacy. For a minimum Tier 1 ratio of 8.5 % (Basel III fully phased-in), a 3 % leverage ratio will only affect banks with RWD below $3\,\%/8.5\,\% = 35.3\,\%$. In other words, the leverage ratio constraint will lead to minimum capital requirements equal to a minimum of 35.3 % in RWD. According to our theoretical model, this is however only adequate for low-risk banks, i.e., banks with asset volatilities of less than about 1.5 %. While the leverage ratio may lead to additional capital requirements for banks with low RWD and hence, on average, lower asset risk, the constraint will still leave high-risk banks with insufficient minimum regulatory capital.

6 Conclusion

When assessing the risk sensitivity of capital-based regulation, it is crucial to differentiate between the cross-sectional sensitivity of risk weights to individual banks' risk at a point in time and the longitudinal sensitivity of risk weights to risk over the business cycle. We propose a model for the relation of both kinds of sensitivity. Particularly, we show that, for a capital standard that is not completely cyclical, cross-sectional risk sensitivity decreases with increases in market risk.

Applying our model to a comprehensive data set that covers both Basel II implementation and the financial crisis, we find that the regulatory standard in place is rather insensitive to changes in risk through the business cycle. Risk weights hardly change with variations in asset risk caused by systematic risk factors. Accordingly, we observe that cross-sectional risk sensitivity is lower in times of higher market risk. Further, we find no indication that Basel II has increased the cyclicality. In this regard, our conclusion contradicts prior studies based on theoretical models and simulation exercises predicting a substantial increase in cyclicality, particularly for IRB banks

Furthermore, even with a differential assessment of longitudinal and cross-sectional risk sensitivity, the capital standard is relatively insensitive to actual risk in the cross section. Our market measure of banks' portfolio risk is only weakly related to the regulatory risk assessment, expressed in the risk-weight density. For example, an increase in asset volatility of 1 % point leads to an average increase in RWD of 2.2 % points (for the year 2012) and only 0.17 % points in capital requirements. Moreover, we find no evidence that Basel II has significantly increased the cross-sectional risk sensitivity. Apparently, for IRB banks, Basel II was merely a tool to reduce their RWA.

Consequences of the weak cross-sectional risk sensitivity may be severe in light of the current minimum capital requirements. As RWA and hence required capital only marginally increase with actual portfolio risk, the stability of banks may be endangered. If banks do not hold additional capital buffers far above the regulatory minimum capital requirements, bank default probabilities exceed acceptable levels, especially in times of financial turmoil.

Our findings carry policy implications for addressing the issues raised above: The regulator may either increase cross-sectional risk sensitivity or increase minimum capital requirements. However, cross-sectional risk sensitivity decreases with increasing market risk for any capital regulation that is not fully cyclical. Hence, maintaining markedly strong cross-sectional risk sensitivity during a crisis may result in oversensitive risk weights during normal times. Further, increasing risk sensitivity usually comes at the price of added complexity. Thus focussing on minimum capital requirements seems to be a more appropriate remedy. Our analyses suggest that substantial increases in capital requirements far beyond Basel III levels are required. This would be in line with the Financial Stability Board, which proposes a total loss-absorbing capacity for global systemically important banks that is set up to 20 % of RWA (Financial Stability Board 2014).

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