Europe Economics

The Uses (and Abuses) of Modelling Adjustments

Modelling adjustments in Internal-ratings Based models of Risk Weights

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1 Introduction

The banking industry and regulators agree that a risk-sensitive prudential capital regime has significant benefits. However, regulators are concerned that the current implementation has created strong incentives for banks to intervene strategically in the determination of risk-weights. Such interventions would affect the calculation of prudential capital requirements, ultimately aimed at limiting the size and, hence, the cost of capital charges, at the expense of the stability of the banking sector.

Europe Economics has been commissioned by the Association for Financial Markets in Europe (AFME) to study the evidence for and against such strategically-motivated interventions in internal ratings-based models.

1.1 Background

The variation in the risk-weights attached to assets is largely driven by genuine differences in risk. The Basel Committee on Banking Supervision (BCBS) estimates that 75 per cent of the variation in credit risk is of this type. Differential supervisory approaches adopted at the national level account for additional variation. Firms may also legitimately disagree on how best to evaluate and hence model particular risks. This form of disagreement was likely much greater in the early days of the regime (which coincided with the credit crunch and significant economic dislocation) than now, but must also be expected to be a permanent feature in a market where innovation is continuous.

However, there are also concerns that firms may be manipulating the current risk-weighting framework through the misuse of internal models, particularly when capital-constrained or facing high capital costs. This has prompted debate as to whether the benefits of a risk-sensitive, internal models-based regime outweigh the associated costs.

Ongoing work at the level of the BCBS is envisaging limitations in the usage of internal modelling. The direction of travel in the proposals to be put forward by the BCBS could result in limiting some of the beneficial impacts of risk sensitivity. Given the value of such risk-sensitivity, there is clearly a need to fully justify their recommended approach. The existence and size of strategically-motivated interventions in internal ratings-based models are central here as combating them is a primary motivation of such measures.

1.2 Our work and findings

Within this context, this report takes a closer look at the use of modelling adjustments as a potential tool for strategic interventions in internal ratings-based models. In particular, we have gathered data on the modelling adjustments made by banks and conducted an empirical analysis of these against the hypotheses cited by the critics of Internal Ratings-Based (IRB) models.

The analysis presented here offers an intuitive and easily applicable framework enabling the assessment of the evidence for — or against — the existence of tactical or strategic interference by a bank's management in the calculation of its risk-weighted assets (RWAs).

We have looked carefully for links between those variables identified in the literature as potential reasons for the gaming of IRB models — such as having a high cost of capital and being capital constrained — and the observed variation in RWA modelling changes.

We have found no evidence for such links. This analysis does not disprove the thought that a bank might engage in such activities — but the finding is wholly inconsistent with the hypothesis that this is common

practice. Based on what we have observed, RWA modelling adjustments are exogenous to bank-specific performance measures. This means that the argument put forward by critics of the IRB approach is at present unproven. Supervisory attention on significant variations in model inputs may, in time, build such a case. Pillar 3 disclosures will help identify the reasons behind changes in RWAs. Supervisors looking at unexplained variation in models should also examine how the framework's implementation varies between different jurisdictions. Equally, increased harmonisation across the Single Market would be welcome. But since our work indicates that the system is far from broken, more drastic action around the IRB at this point looks unjustified.

1.3 Organisation of this study

The study first presents an overview of the debate on the role of internal modelling in the determination of capital requirements. We then describe a thorough statistical analysis involving bivariate and multivariate methodologies. The latter include cross-sectional and panel econometric estimations aiming at capturing the determinants of modelling adjustments both statically at a given period as well as in a more dynamic context across banks and through time. In this work we are searching for evidence for significant relationships between bank-specific performance measures and the modelling adjustments identified for the banks included in this study.

The report is structured as follows:

- Chapter 2: The debate on internal modelling & risk-sensitive capital requirements — this section summarises the main arguments for a risk-sensitive regime, including the identification of the costs of desensitising the existing regime, and also presents the criticisms raised around the reliance on internal models to determine risk weights in such a risk-sensitive regime.
- Chapter 3: Methodological Framework — this section presents our approach to addressing the debate on the use of IRB models to underpin the risk-sensitivity of capital requirements, along with the development of our testable hypotheses.
- Chapter 4: Quantitative Analysis — this section presents the results of our statistical and econometric analyses along with the main conclusions of our findings.

The more detailed results of our econometric analysis are set out at the Technical Appendix at the end of this study (Chapter 5).

2 The Debate on Internal Modelling & Risk-Sensitive Capital Requirements

2.1 The importance of capital regulation

Banks need to maintain capital and liquidity buffers against shocks. Whilst a strong capital position means that more unexpected events can likely be survived, banks' managements also need to generate adequate returns on capital in order to internally finance future growth and to satisfy investors who have provided that capital. Policy-maker concerns around the potential impacts on depositor confidence and the functioning of the banking system in case of the failure of an individual bank (in itself, or through propagation to other banks via contagion or some other chain reaction) have been used to justify the regulation of prudential capital.[1]

A well-functioning banking system ought to be able to respond well to shocks, therefore the institutions comprising it need to have the necessary tools to support their solvency during difficult times. As a result, prudential capital regulation has been designed to enhance the safety of banks, by ensuring their ability to absorb losses while integrating the presence of risk.[2] The focus of prudential capital regulation, then, is to reduce the risks associated with banks' operations by alleviating potential threats to their solvency.

The amount of capital that a bank needs is related to both the size and riskiness of its assets and must be sufficient to provide a buffer to absorb unexpected liquidity and capital needs generated by shocks. The higher the risks associated with a bank's assets then, other things being equal, the more capital a bank will be required to hold against them to account for the greater probability that they will experience losses. Conversely, the lower the amount of risk, the less capital that needs to be held against the assets.

Within the current framework, regulatory capital requirements are calibrated to the riskiness of bank assets.[3] With regards to credit risk[4] this calibration process may involve the use of standardized risk-weights or IRB risk-weights.[5] The former are based on regulatory-defined risk weightings (also making use of external ratings provided by credit rating agencies), while the latter are based on a bank's internal risk assessment of each of its exposures. The IRB risk-weights have *more* risk-sensitivity as they are tailored to the idiosyncrasies of each bank's exposures.

However, in the wake of the financial crisis, the extent to which prudential capital requirements accurately reflect a bank's actual risk exposure has been subject to further scrutiny. Thus, as a result of the efforts being undertaken to ensure the resilience of banks in the future, a considerable debate has emerged on the relative merits of risk-sensitive capital requirements, and more specifically on the role that banks' internal models should play in determining regulatory capital requirements.

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1 In this paper we accept the regulation of prudential capital as a fact. For an example of arguments *against* the need for such regulation, see the 2013 paper "Do we need regulation of bank capital: Some evidence from the UK", by Forrest Capie and Geoffrey Wood, http://www.lse.ac.uk/fmg/events/financialRegulation/LFR18G_Wood.pdf.

2 See Sharpe, W. (1978), "Bank capital adequacy, deposit insurance and security values" Journal of Financial and Quantitative Analysis, Vol 13, p.701–718.

3 See Vallascas, F. and Haggendorff, J. (2013), "The risk sensitivity of capital requirements: Evidence from international sample of large banks" Review of Finance, Vol 42, p.1-42.

4 Credit risk is most simply defined as the potential that a bank borrower or counterparty will fail to meet its obligations in accordance with agreed terms.

5 See Bank of International Settlements (2000), "Principles for management of credit risk".

2.1.1 The Basel I and Basel II accords

The first international accord on bank capital (Basel I, 1988) suggested that the total capital holding of a bank should represent at least 8 per cent of its credit risk exposure, as measured by its RWAs. In these early days of prudential bank regulation credit risk was the only type of risk covered.

To calculate RWAs, a simple set of weights was devised ranging from nil per cent for credit exposures towards OECD governments and public sector entities to 100 per cent for highly risky exposures, such as unsecured loans supported only by the borrower's creditworthiness, rather than by a type of collateral.[6] Nevertheless, the scheme introduced by Basel I proved in time over-simplistic, as well as prone to regulatory arbitrage.[7,8]

Aimed at addressing the above issues, the second accord on bank capital (Basel II, 2004) allowed for more granularity in the calculation of RWAs. The latter could now be differentiated, within the same type of exposure, depending on the actual credit risk of borrowers. A further innovation introduced by Basel II was that to estimate risk, banks could choose between the standardised approach and their own internal assessments (i.e. an internal ratings-based approach) provided they met strict conditions and had supervisory approval to do so.

2.1.2 The financial crisis — Basel 2.5 and Basel III

In the aftermath of the 2007-2009 financial crisis, several steps were taken towards enhancing the Basel II framework (also referred to as Basel 2.5).[9] The most significant measures involved changes to the market risk framework (regarding trading book exposures) and upwards re-adjustments of both standardized and IRB risk-weights for securitisation and re-securitisation positions.[10]

In addition to introducing liquidity and leverage requirements, the Basel III reforms have primarily focused on improving the numerator of the capital ratios by requiring banks to hold more and higher quality capital; in contrast, limited changes have been suggested to the denominator (i.e. the risk-relative weights used in the computation of RWAs) to date.[11]

However, the use of "adjusted" capital ratios[12] as well as "plain" unweighted capital ratios (i.e. the leverage ratio) have also been advocated with the intention of resolving any 'flaws' in the use of risk-weighted measures.[13] The leverage ratio, in particular, is expected to reduce any impacts due to biases attributed to internal modelling methods as it is not affected by the risk weights of different assets.

2.2 Addressing RWA variance

Academics and regulators have placed risk-weighting methodologies under scrutiny in light of observed differences in RWA density (i.e. the ratio of RWAs over total assets) across banks and jurisdictions that

6 For instance, for an unsecured £1,000 loan which requires a risk weight of 100 per cent, the RWA equals £1,000. Using the minimum 8 per cent capital requirement suggests that the total capital holding of the bank in relation to the unsecured loan of £1,000 must be £80.

7 For instance, a "flat" 100 per cent risk weight for all non-financial companies incentivized banks to focus on high-risk borrowers in order to maximize interest revenues in the short term, while increasing the potential for future defaults and credit losses.

8 See Basel Committee on Banking Supervision (2013a), "The regulatory framework: Balancing risk sensitivity, simplicity and comparability".

9 See BCBS (2009), "Enhancements to the Basel II framework".

10 Re-securitisations can be defined as securitisations that have underlying securitisation positions.

11 See Bruno et al. (2014).

12 "Adjusted" capital ratios impose floors and caps to the risk weights used by banks.

13 See de Longevialle B., Heriard-Dubreuil, E. and Grunspan,T. (2008), "Towards comparable Basel II ratios: Standard & Poor's risk-adjusted capital framework" in Resti A. (ed.), Pillar II in the New Basel Accord - The Challenge of Economic Capital, RiskBooks, London, 397-422.

seemingly had similar types of assets. These concerns are based on the variation of results from a number of hypothetical portfolio exercises which required banks to estimate their capital requirements for a given set of assets with identical characteristics.

In general, cross-bank RWA variance can be largely explained by the business mix of individual institutions.[14] Indeed, studies by the BCBS and the European Banking Authority (EBA) indicated that up to three quarters of the variability in risk weights for credit risk is driven by differences in underlying risk arising from banks' asset composition.[15,16]

Thus, divergent levels of RWAs can be justified when attributable to different levels of exposure to risks across institutions; i.e. natural — and desirable — differences in business models and portfolios would be *expected* to result in observable RWA differences. Therefore, RWA variation of this type is consistent with the greater risk sensitivity intended by the Basel II framework.

However, different national implementations of the Basel agreement, firms' risk management practices and divergent supervisory practices[17] along with the banks' modelling choices[18] also contribute (although to a lesser extent) to the observed variation of RWAs across banks.[19] In particular, the choice of IRB approaches (i.e. foundation versus advanced IRB) as well as risk parameter changes and other modelling choices[20] have been portrayed as the most prominent aspects of methodological influences on the calculation of RWAs across banks.

An extensive review of modelling practices by the Institute of International Finance (IIF) RWA Task Force in 2014 indicated that, while variances in RWA outcomes can indeed be large, there are numerous potential explanatory factors, including risk management policies and practices,[21] as well as differences between banks' portfolios. For example, differences in recovery strategy with the same counterparty would result in different Loss Given Default, and hence differences in the value of risk-weighted assets. Hence, variation in credit management practice can give rise to legitimate variance in RWAs. Nevertheless, additional convergence could be helpful.

Within this context, it is suggested that there is still scope for further harmonisation of modelling approaches, for instance through closer coordination among supervisors when validating IRB models.[22,23] In particular, in 2014, the EBA launched a consultation on its draft regulatory technical standards (RTS) on assessment methodologies for the IRB approach.[24] These draft RTS are to be embedded in day-to-day

[14] See Cannata, F., Casellina, S. and Guidi, G. (2012), "Inside the labyrinth of Basel risk-weighted assets: How not to get lost" Banca d'Italia working paper No 132.

[15] Basel Committee on Banking Supervision (2013b), "Analysis of risk-weighted assets for credit risk in the banking book".

[16] EBA, (2015) "Results from the 2014 low default portfolio (LDP) exercise".

[17] See European Banking Authority (2013), "On the specification of the assessment methodology for competent authorities regarding compliance of an institution with the requirements to use the IRB Approach in accordance with Articles 144(2), 173(3) and 180(3)(b) of Regulation (EU) No 575/2013".

[18] See Basel Committee on Banking Supervision (2013b), "Analysis of risk-weighted assets for credit risk in the banking book".

[19] The inherent difficulty in forecasting can also be a potential source for the observed variation in RWAs. Banks can address this difficulty by introducing margins of conservatism to their estimates, which supervisors can then challenge.

[20] These refer to aspects such as the choice of reference data, probability of default master scale, the adjustments for cyclical effects and the treatment of low default portfolios.

[21] See also Carr, B. (2015), "Risk modelling: Convergence needed, but some variances are legitimate", Journal of Risk Management in Financial Institutions, Vol 9, p.323-331.

[22] Ledo, M., (2011), "Towards more consistent, albeit diverse, risk-weighted assets across Banks", Estabilidad Financiera, No. 21, p. 49, Banco de España.

[23] Arroyo J., Colomer I., Garcia-Baena R. and Gonzalez-Mosquera L. (2012), "Comparing risk-weighted assets: the importance of supervisory validation processes" Estabilidad Financiera, Vol 22, Banco de España.

[24] See European Banking Authority (2013), "On the specification of the assessment methodology for competent authorities regarding compliance of an institution with the requirements to use the IRB Approach in accordance with Articles 144(2), 173(3) and 180(3)(b) of Regulation (EU) No 575/2013".

supervisory practices and consulted by the authorities in their assessment of an institution's compliance with minimum IRB requirements. They would also be used when a bank:

- initially applies to use the IRB approach;
- applies to use the IRB approach for certain types of exposures;
- applies for implementation of material changes to the IRB approach; or
- applies to resume less sophisticated approaches.

Additionally, within the context of increased harmonisation, the EBA's ongoing work programme aims to contribute to a consistent implementation across the EU of regulatory provisions related to topics such as the definition of default, and Probability of Default (PD) and Loss Given Default (LGD) estimation. The expected output of their work will result in the enhancement of IRB models and the reduction of RWA variance.[25]

Numerous other safeguards to ensure that regulatory capital based on internal models is sufficient have also been put into place along with stress testing requirements implemented in many EU jurisdictions.[26] Another significant initiative relates to the benchmarking of RWA outcomes, which aims to assess the consistency and comparability in RWAs produced by institutions' internal modelling approaches.[27] Last, IRB models are also extensively scrutinised by supervisors prior to approval, while banks have to demonstrate that these models are integrated into their internal decision making, management and governance processes and are not solely used for the purpose of calculating capital requirements.

We can see therefore that the cross-bank variation in RWAs is largely driven by legitimate differences in banks' business models and variation in the translation of these into modelled risk-weights and also that work is underway to reduce divergence within the regulatory and supervisor framework. Even so, some regulators continue to express concern over the potential for strategically- or tactically-motivated interventions in the calculation of IRB risk weights.

The progress report on Basel III highlights the necessity for fostering harmonisation of capital regulations across member jurisdictions. The report also notes that all Committee members have implemented risk-based capital regulations and that efforts are now underway to identify areas which by their nature are considered by the BCBS to not be amenable to modelling, and to use this to justify the imposition of a capital floor.[28] In January 2016, the GHOS (Group of Central Bank Governors and Heads of Supervision) agreed that the BCBS would complete its work to address "the problem of excessive variability in risk weighted assets" and that this would involve, inter alia, "setting additional constraints on the use of internal models for credit risk".[29]

2.2.1 The link between risk weights and actual risk exposure

A related question is whether risk weights sufficiently reflect a bank's actual risk exposure. Views regarding the extent to which RWAs are reflective of a bank's true risk are mixed. Various market-based measures have been deployed to make such an assessment, but with ambiguous results.

Risk weights are weakly related to certain market-based measures of risk, although this relation appears to have been stronger before the 2007-2009 financial crisis.[30] However, most of these measures are driven by

[25] See EBA (2015), "The EBA 2016 annual work programme".
[26] For instance, Pillar 2 requirements address the potential of risks not being fully reflected under Pillar 1 calculations.
[27] See EBA (2015), "Final Draft Implementing Technical Standards on benchmarking portfolios, templates, definitions and IT solutions under Article 78 of Directive 2013/36/EU".
[28] See BCBS (2014), "Seventh progress report on adoption of the Basel regulatory framework" http://www.bis.org/press/p141112a.htm.
[29] See GHOS press release 11 January 2016: https://www.bis.org/press/p160111.htm.
[30] See Bruno, B., Nocera, G. and Resti, A. (2014), "The credibility of European banks' risk-weighted capital: Structural differences or national segmentations?" Working paper and Das, S. and Sy, A.N.R. (2012) "How risky are banks' risk weighted assets? Evidence from the financial crisis" IMF Working Paper No. WP/12/36.

equity performance and thus are imperfect proxies of overall bank risk. This is due to the fact that the recent increased volatility of banks' stock prices is likely to have inflated these risk measures, ultimately driving the loosening of their relation to RWAs post-crisis.

With regards to measures of bank risk that are not stock market-based, it has been hypothesized that Basel II requirements had an asymmetric impact on low- and high-risk banks. Ultimately, this resulted in riskier banks holding an insufficient amount of capital. More specifically, evidence suggests that banks with low-risk loan portfolios reduce their capital requirements when adopting the IRB approach, whereas banks with high-risk loan portfolios are not required to hold significantly more capital.[31] Thus, under Basel II, high-risk banks ran the risk of holding insufficient capital.

Discrepancies between the standardised, regulatory assessment of risk-weights and those generated through internal models (which should be fully reflective of the economic risks inherent in banks' assets) means there is the potential for banks to engage in capital arbitrage.[32] Generally, the more capital a regulator requires a bank to hold, the higher the opportunity cost to the bank as this capital could be used for other operational purposes that can generate returns.

This means that banks that view raising capital as proportionally more expensive have an incentive to strategically lower the reported value of RWA density relative to their portfolio risk. As prudential capital requirements are largely a function of RWAs, this would enable them to increase their reported capital ratios without the need to raise any additional capital simply by lowering the denominator of the ratio calculation. Ultimately, such activities may result in a riskier banking sector, where capital requirements bear a less than ideal relation to the economic fundamentals underlying the true risks of bank portfolios.

Overall, risk weighted capital ratios are informative about bank resilience, but there are claims that they can also be subject to strategic changes by banks aiming to appear more stable when under stress.[33] Nevertheless, such issues could be alleviated by higher levels of supervisor scrutiny. The latter has been associated with better and more transparent risk reporting, particularly for large banks due to the negative systemic externalities that would be produced in case of failure. In a similar spirit, it is argued that banks that face more intense competition are under increased scrutiny from their investors and competitors, ultimately preventing them from using their internal models strategically.[34]

[31] Vallascas, F. and Haggendorff, J. (2013), "The risk sensitivity of capital requirements: Evidence from international sample of large banks" Review of Finance, Vol 42, p.1-42.

[32] See Merton, R. C. (1995), "Financial innovation and the management and regulation of financial institutions" Journal of Banking and Finance, Vol 19, p.461–481.

[33] Mariathasan, M. and O. Merrouche (2013), "The manipulation of Basel risk-weights" Centre for Economic Policy Research, Discussion Paper No 9494.

[34] Mariathasan, M. and O. Merrouche (2013), "The manipulation of Basel risk-weights" Centre for Economic Policy Research, Discussion Paper No 9494.

Table 2.1: The Basel accords and the IRB approach

Basel Treaty	Key elements
Basel I	Standardised risk-weights.
Basel II	IRB risk-weights introduced as an alternative to standardised risk weights.[35] Overall, the IRB approach encompasses: • a classification of exposures by broad risk type; • estimation of probability of default, loss given default, exposure at default and maturity which a bank must provide for each exposure class; • a risk-weight function which provides risk weights for given sets of these components; • a set of minimum requirements that a bank must meet in order to be eligible for IRB treatment for that exposure; and • a supervisory review of compliance with the minimum requirements across all exposure classes.
Basel II.5	Minor changes introduced in IRB methodologies mainly related to securitization and re-securitization exposures. More specifically: • banks using the IRB approach to securitisation are required to apply higher risk weights to re-securitisation exposures; • a bank cannot recognise ratings, either standardised or IRB, that are based on guarantees or similar support provided by the bank itself; • banks are required to meet specific operational criteria in order to use the risk weights specified in the Basel II securitisation framework; and • clarification of when liquidity facilities[36] in the IRB approach may be treated as senior securitisation exposures.
Basel III	Basel III introduced: • requirement to hold more and higher quality capital; • new capital charges imposed for credit valuation adjustments and wrong-way risk[37] within IRB formulas; • leverage ratio; and • liquidity requirements.
Ongoing BCBS Work	The work of the BCBS is ongoing and is looking at reducing RWA variance. It has discussed restricting the use of internal modelling in areas that, in the BCBS's view, are not amenable to it. In such cases, internal modelling would be restricted and banks would also have to apply a capital floor based on standardised approaches.

Source: Europe Economics research.

2.3 The value of risk-sensitivity in capital regulation

Against this backdrop, proponents of risk-sensitivity in capital requirements argue for the continuation of the IRB approach and internal models. A diminished role for internal models could dilute risk-sensitivity — which provides the proper incentives for banks to have better knowledge of and control over their risk, and ultimately enhances the stability of the financial system.[38]

[35] See BCBS (2001), "The internal ratings-based approach".

[36] A liquidity facility is a letter of credit, standby bond purchase agreement or other arrangement used to provide liquidity to purchase securities, typically variable rate demand obligations, that have been tendered to the issuer or its agent but which cannot be immediately remarketed to new investors. The provider of the liquidity facility, typically a bank, purchases the securities (or provides funds to the issuer or the remarketing agent to purchase the securities) until such time as they can be remarketed.

[37] Wrong-way risk occurs when "exposure to a counterparty is adversely correlated with the credit quality of that counterparty". In short it arises when default risk and credit exposure increase together.

[38] See for example IIF (2015), "Risk and capital: The essential nexus".

Specifically, where bank capital is linked to risk in a coherent and robust way, it will be allocated in an effective manner, allowing long term sustainable and stable growth in the economy.[39] It follows that revisions which reduce the role of internal modelling are likely to reduce the extent to which they accurately reflect bank risk, which would ultimately affect capital allocation. This potential for misallocation of capital to the economy could hinder rather than promote growth and sustainability.[40]

It is also argued that the removal of risk-sensitive capital requirements, or a reduction in their risk sensitivity, may drive banks operating in low risk environments to increase margins on their best credit risk exposures and to securitise such exposures, ultimately resulting in smaller bank balance sheets and more credit intermediation taking place outside the regulated banking sector by non-bank financial institutions (NBFIs).[41] The above would not be conducive to enhancing growth as a higher portion of an economy's credit risk exposure being held by NBFIs is likely to make the credit intermediation process less resilient in turbulent times and more pro-cyclical since non-banks may not have the same ongoing commitment to provide financing as regulated banks have.[42]

Moreover, if non-bank financing is increasingly involved in conventional bank-like activities, such as transforming maturity[43] or liquidity,[44] it can become a source of systemic risk, both directly and through its interconnectedness[45] with the banking system.[46] Whilst considerable effort is being put towards reforming the non-bank financing industry in order to enhance its stability and reduce its pro-cyclicality, it remains early days.

Along similar lines, less risk-sensitive approaches are criticised for their potential to introduce new hazards into the banking system, as well as re-introduce some old ones.[47] More specifically, in failing to reflect risk properly, simple approaches have been criticised due to their potential to give rise to adverse selection concerns and create distortions in pricing signals. This is argued to be the likely result of banks becoming more incentivised to look for assets further down the credit curve (e.g. high-yield corporate lending, unsecured consumer lending) where they would earn higher spreads and generate a better return but would not incur an added capital penalty. In so doing they would also be incentivised to over-price credit for well-rated borrowers and under-price it for the more marginal ones.

Ultimately, the above would result in insufficient capital levels as, although standardised approaches tend to inflate the required capital on well-rated credit, they often require insufficient levels of capital requirements

[39] See for example Institute of International Finance (2014), "Risk-sensitivity: The important role of internal models".

[40] See for example AFME (2015), "European Commission Consultation on the possible impact of the CRR and CRD IV on bank financing of the economy".

[41] See for example the Danish Banking Association in collaboration with the Swedish Bankers' Association, the Dutch Banking Association and the Federation of Finnish Financial Services (2015), "Important to keep a risk-based approach for capital requirements".

[42] NBFIs are financial institutions that do not have a full banking license or are not supervised by a national or international banking regulatory agency. NBFIs facilitate bank-related financial services, such as investment, risk pooling, contractual savings, and market brokering. See Carmichael, J. and Pomerleano, M. (2002), "Development and regulation of non-bank financial institutions" World Bank Publications No 12.

[43] Maturity transformation relates to when banks use deposits, which are normally short term, to fund loans that are longer term.

[44] Liquidity transformation is a concept similar to maturity transformation that entails using cash-like liabilities to buy harder-to-sell assets such as loans.

[45] Evidence suggests that the interconnectedness between the banking and the non-bank financial sectors reached its peak during a short period prior to the 2007-2009 crisis. See for example, Financial Stability Board (2015), "Global shadow banking monitoring report 2015".

[46] See for example Financial Stability Board (2015), "Transforming shadow-banking into resilient market-based finance".

[47] Institute of International Finance (2014), "Risk-sensitivity: The important role of internal models".

for high risk positions. As a result, the standardized approach has been criticised for leading to lower capital requirements for risky banks[48] and increasing the potential for banks to become more risky.[49]

Similarly, there is evidence to suggest stronger correlations of loan performance measures with Basel II/III risk weights than with Basel I risk weights. This indicates that, relative to the standardized approach, the IRB approach is more likely to improve the alignment of regulatory capital with a bank's asset risk and allow for better comparison of banks' asset quality.[50]

Moreover, reduced risk-sensitivity in capital requirements has been suggested to lower banks' incentives to invest in understanding and modelling the risk profile of their customers. More specifically, within a framework specified by regulators, IRB methods allow for idiosyncratic differences to be accounted for so as to reflect structural (e.g. legal or macroeconomic factors) and other characteristics, such as the nature and depth of the relationship between the bank and the customer.[51]

Thus, aggregating all bank customers under common risk profiles is likely to exacerbate capital misallocation by preventing creditworthy loan applicants from securing sources of financing, as well increasing the risk exposure of banks by lowering the amount of prudential capital for high-risk credits.

Such excessive standardization may also create herding behaviour. More specifically, the strength and stability of the financial system is supported by the presence of a diverse group of credit providers with their own core capabilities and risk appetites, which are nevertheless scrutinized by rigorous supervision. Within this context, a high risk-appetite by a financial institution is not necessarily threatening to the well-functioning of the banking system provided that a sufficient amount of prudential capital has been allocated to each exposure. In contrast, if all players used either the same model, or the same risk weights based on credit ratings provided by a small group of rating agencies, then the resultant pro-cyclicality could quickly translate model risk into systemic risk.[52]

2.4 Conclusions

The BCBS is looking to propose limitations in the usage of internal modelling (see Table 2.1, last row). As shown above, however, there are a number of legitimate driving forces behind RWA variation and there are considerable merits in maintaining the current level of risk-sensitivity in capital regulation through the use of internal models.

The direction of travel of the BCBS's work could result in limiting some of the beneficial impacts of risk sensitivity. Given the value of such risk-sensitivity, there is clearly a need to fully justify the BCBS's recommended approach. The existence and size of strategically-motivated interventions in internal ratings-based models are central here as combating them is the ultimate motivation of such measures. Within this context, this report takes a closer look at the use of modelling adjustments as a potential tool for strategic interventions in internal ratings-based models.

[48] See for example Hakenes, H. and Schnabel, I. (2011), "Bank size and risk-taking under Basel II", Journal of Banking and Finance Vol. 35, p.1436-1439.

[49] See Bakarova, I. and Palvia, A. (2014), "Do banks' internal Basel risk estimates reflect risk?" Journal of Financial Stability, Vol 13, p.167-179.

[50] Bakarova, I. and Palvia, A. (2014), "Do banks' internal Basel risk estimates reflect risk?" Journal of Financial Stability, Vol 13, p.167-179.

[51] See for example European Banking Federation (2014), "Study on Internal Rating Based models in Europe".

[52] See for example Financial Stability Board (2010), "Principles for reducing reliance on CRA Ratings".

3 Methodological Framework

3.1 Introduction

The aim of this section is to provide a link between the qualitative arguments presented above and the quantitative analysis presented the following chapter. Accordingly, this section includes:

- an overview of the implications of the two sides of the debate; and
- a list of the hypotheses to be tested.

3.2 Implications of the debate

There is wide agreement on the necessity of prudential capital regulation. However, as the previous chapter highlights, the optimal structure of such regulation, and in particular of banks' capital charges, has become the source of substantial disagreement across market participants and policy makers. More specifically, the introduction of internal model-based capital regulation has been an important innovation in the financial sector[53] as well as the subject of considerable debate over its effectiveness.

Overall, proponents of IRB models argue that an efficient allocation of resources within a complex financial system requires the use of complex risk measurement methodologies — and that these therefore need to be bespoke to a particular bank and not based on standardised, simpler approaches.

Whilst critics worry that this complexity provides latitude for regulatory arbitrage — allowing banks to make tactical adjustments when under some form of stress — IRB modelling is already subject to a substantial degree of supervisory scrutiny. Such strategic modelling interventions would be facilitated by limits in the transparency of underlying inputs within IRB models as, despite having been initially validated by supervisory authorities, a bank may have more than 100 different risk models with thousands of parameters in place.[54] As a result, the surveillance of all such future calibrations by the supervising authorities can be challenging. Nevertheless, the supervisor's approval is required when material changes to internal modelling are proposed.

It is thus implied that, despite its suitability to better address bank-specific risk exposures and ultimately increase the stability of the banking system,[55] the use of IRB models is subject to informational and incentive constraints that might hinder efficient implementation. In principle, in a world with no information or enforcement problems, tailoring a bank's capital requirements to the idiosyncratic features of its risk exposures should improve welfare. Under enforcement limitations, however, it could be argued that coarser regulation is preferable.[56]

The resolution of this dichotomy must be vested in empirical evidence. In particular, an assessment is needed of any evidence for or against tactical or strategic interference by banks' in the calculation of their RWAs. Several determinants of variation in RWAs are identified in literature, including:

[53] See for example Behn, M., Haselman, R. and Vikrant, V. (2014), "The limits of model-based regulation" SAFE Working Paper Series No. 75.

[54] See example Behn, M., Haselman, R. and Vikrant, V. (2014), "The limits of model-based regulation" SAFE Working Paper Series No. 75.

[55] See for example. Basel Committee on Banking Supervision (2006), "International convergence of capital measurement and capital standards — A revised framework" Bank for International Settlements, Basel, Switzerland.

[56] See for example Glaeser, E. and Shleifer, A. (2001), "A reason for quantity regulation" American Economic Review. Vol 91, No 2, p.431–435.

- The business model, risk management practices and asset mix of the bank.
- The effect of complying with various Basel and other regulatory requirements (i.e. EU- or national-level requirements implementing the Basel requirements).
- The effect of IRB model assumptions and parameters, and the changes therein.

The first two sources of variation are not expected to be grounds for the strategic alteration of the value of RWAs. Each financial institution has a different risk profile which results from several interconnected elements, such as its business model, lending choices and the influence exerted by external macroeconomic factors. Regulatory, supervisory and institutional factors also affect the risk profile of a bank and can naturally lead to legitimate differences in RWA levels across banks and jurisdictions.[57]

Investigating IRB model changes offers an intuitive and easily applicable framework to examine the extent to which these changes are linked to incentives to strategically adjust RWAs. The debate identifies circumstances where adjustments to model parameters could be made for strategic or tactical reasons as follows:

- The management of a capital-constrained bank (e.g. a bank with limited headroom above the regulatory minimum capital requirement) may have an incentive to engage in changes in modelling assumptions so as to reduce the overall amount of RWAs. This would lower the bank's prudential capital requirements and thus the opportunity cost of holding more Tier 1 capital than the institution deems necessary. This is motivated by the fact that raising such capital can be particularly expensive for a bank.[58] Alternatively, such an incentive could arise abruptly, such as in the case of a sudden increase in the bank's cost of capital or where the cost of capital becomes uncomfortably high.[59]
- Similarly, a bank experiencing a significant drop in profitability could be tempted to change its IRB modelling assumptions so as to limit having to raise Tier 1 capital and the implied additional costs. This could bolster the bank's future profitability ratios, but at the expense of its solvency protection.
- Last, a bank might be incentivised to make modelling adjustments to lower its total RWAs and, thus, conserve its risk-appetite. This would enable it to maintain, or even extend, its investment exposure to particularly risky assets so as to generate significant returns. The consequences of such actions would be more pronounced in case the bank is highly leveraged: on the one hand, leverage magnifies profits when asset returns exceed the costs of borrowing, on the other hand, losses are magnified when the opposite is true (e.g. during a downturn period in economic activity).

3.3 Development of testable hypotheses

The discussion in the previous section implies that if banks are using adjustments to IRB models to game reported RWAs then this should show up in significant, systematic relationships between bank-specific performance measures and the modelling adjustments made by banks. Evidence of such gaming could mean that, despite its intrinsic — and generally accepted — benefits, the IRB approach involves enforcement limitations and, particularly, incentive constraints. These would limit the adequate calculation of RWAs and, consequently, banks' prudential capital requirements.

On the other hand, the opposite can be inferred if the presence of a specific relation between IRB modelling adjustments and performance measures is not supported by empirical evidence. This would support the view that modelling adjustments are exogenous to the relevant bank performance indicators and, thus, not identifiable as being driven by strategic management choices.

[57] For instance, legal frameworks, such as bankruptcy and foreclosure laws, as well as regulatory provisions, e.g. Loan-to-Value (LTV) and accounting policies, play a significant role in determining a bank's risk profile. See for example Nadal J. and Serrano, J. (2012), "The new importance of risk-weighted assets across Europe" Accenture special report.

[58] See Kauko, K., (2012), "Why is equity capital expensive for banks?" Bank of Finland working paper.

[59] Such rises in the cost of capital may be driven from factors controllable by the bank, such as increased debt issuance or dividend pay-outs, or uncontrollable by the bank, such as increases in the level of interest or tax rates.

4 Quantitative Analysis

This chapter presents our quantitative analysis of the determinants of modelling changes in the calculation of RWAs. First, we explore the relationship of modelling changes with bank-specific performance measures that we consider the most representative indicators of profitability, capital constraints and cost of capital. Subsequently, this analysis is extended through the implementation of various econometric estimations. These aim at capturing the effects of bank-specific performance measures on modelling changes while accounting for the simultaneous influence exerted by other factors.

This chapter covers the following topics:

- Data collection.
- Descriptive statistics.
- Econometric estimations.
- Conclusions.

4.1 Data collection

4.1.1 Modelling adjustments in the calculation of RWAs

The aim of our quantitative analysis is to investigate the evidence for strategic interventions in the mechanics of IRB models used by banks. Such interventions would ultimately affect reported RWAs. In general, banks may use:

- IRB approaches for credit risk;
- internal model methods (IMM) for counterparty credit risk;
- advanced measurement approaches (AMA) for operational risk; and
- internal models approaches (IMA) for market risk.[60]

Our main variable of interest (i.e. our dependent variable) is that of credit risk modelling updates.[61] Credit risk is critical to the determination of RWAs, and this is where the debate to date has focused. Such modelling updates occur throughout the fiscal year and affect the overall size of reported RWAs. The RWA flow statements, which can be reported within Pillar 3 reports, include the identification of these alongside other items reconciling the change in RWAs.[62]

The disclosure of Pillar 3 reports became mandatory in the advent of Basel II in 2004. However, the disclosure of a RWA flow statement remained voluntary and its format was not standardized. This will change in the near future, as the January 2015 revised Pillar 3 requirements make it mandatory for banks to disclose RWA flow statements in a fixed format, with this scheduled to become effective by the end of 2016 in the following form:

[60] See https://www.eba.europa.eu/regulation-and-policy/model-validation.

[61] Such adjustments may also be referred to as model updates, model changes, risk parameter changes etc.

[62] Pillar 3 of the Basel framework aims to promote market discipline through regulatory disclosure requirements relating to a bank's regulatory capital and risk exposures. See BCBS (2014), "Review of the Pillar 3 disclosure requirements".

Table 4.1: Indicative RWA flow statement

		RWA amounts
1	**RWA as at end of previous period**	
2	Asset size	
3	Asset quality	
4	Model updates	
5	Methodology and policy	
6	Acquisitions and disposals	
7	Foreign exchange movements	
8	Other	
9	**RWA as at end of reporting period**	

Source: BCBS (2015) "Revised Pillar 3 disclosure requirements".

The elements of the RWA flow statement are defined as follows:

- Asset size refers to organic changes in book size and composition (including origination of new businesses and maturing loans) but excluding changes in book size due to acquisitions and disposal of entities.
- Asset quality refers to changes in the assessed quality of the bank's assets due to changes in borrower risk, such as rating grade migration or similar effects.
- Model updates is our main variable of interest. It refers to updates that reflect recalibrations of parameters or significant changes in model scope. More specifically, model updates may be related to:
  - changes due to model implementation;
  - changes in model scope; and
  - any changes intended to address model weaknesses.
- Methodology and policy refers to changes due to methodological changes in calculations driven by regulatory policy changes, including both revisions to existing regulations and new regulations.
- Acquisitions and disposals refers to changes in book sizes due to acquisitions and disposal of entities.
- Foreign exchange movements refers to changes driven by market movements such as foreign exchange movements.
- Other refers to changes that cannot be attributed to any other category.

The above clearly suggest that the parameter referring to "Model updates" would be the most likely candidate to capture potential interventions in IRB methodologies. This is related in large part to the expected ability (or inability) of the internal and/or external (i.e. by auditors and/or supervisors) review processes to check and understand the changes being made. Any adjustments in the "Methodology and policy" category should simply be those changes in modelling methods driven by shifts in regulation. Whilst there may be greater scope for strategic interventions here than in the "Asset size" and "Acquisitions and disposals" categories, we still expect it to be significantly less than where we have looked.

More specifically, the IRB approach offers two credit risk evaluation methodologies:

- Foundation IRB approach (FIRB approach).
- Advanced IRB approach (AIRB approach).

Under both of these, internal estimates of parameters such as PD, LGD, exposure at default (EAD) and the effective maturity of exposures are produced.[63] The main difference is that banks that adopt the FIRB approach only calculate PDs and have the other parameters set by their regulators, whereas banks that adopt the AIRB approach calculate all of their risk parameters using their internal models. Thus, modelling adjustments are expected to reflect changes in the calculation of these parameters, ultimately affecting the size of reported RWAs. In contrast, modelling adjustments are not expected to be related to the risk

[63] See Allen & Overy (2014), "Internal ratings based approach to credit risk in the banking book", Client Briefing paper No 4 and BCBS (2005) "Basel II: International convergence of capital measurement and capital standards: A revised framework".

profile of the bank as, for instance, the influence exerted on RWAs from low portfolio quality would be captured by the asset quality metric.

In cases where Pillar 3 reports were not available, information on modelling adjustments was obtained from banks' annual reports. This effort was partly confounded by the fact that not all banks are obliged to disclose RWA flow statements within Pillar 3 or annual reports and early adopters of the revised Pillar 3 requirements were particularly few.[64]

The following figure provides an illustrative example of an identified RWA flow statement within the 2014 annual Pillar 3 report of a major EU financial institution (Barclays).

Table 4.2: Illustrative RWA flow statement

	Total RWAs for credit risk (£ billion)
As at 1 January 2014	442.5
Book size	-17.4
Acquisitions and disposals	-14.5
Book quality	-5.3
Model updates	11.9
Methodology and policy	-12.9
Foreign exchange movements	-1.5
Other	0.9
As at December 2014	401.9

Source: Europe Economics research (extract from Barclay's 2014 Pillar 3 report).

4.1.2 The data set

Our data set was obtained from RWA flow statements found in Pillar 3 reports. Overall, we were able to create a sample of 40 banks[65] with the required information on the annual impact of credit risk modelling adjustments for the year 2014.[66] We also attempted to gather the same information for 2013. However, these data were markedly less available.[67] This becomes particularly evident in a 2013 report of the Enhanced Disclosure Task Force (EDTF) of the Financial Stability Board (FSB).[68] The report follows a 2012 survey-based study on the quality of bank disclosures and seeks to determine whether there is scope for further improvements. It is concluded that:

- only 23 per cent of banks included in the survey had implemented an RWA flow chart by 2012, with an additional 19 per cent expected to implement the RWA flow chart by 2013 and 58 per cent having no implementation plans (this is likely to change by the end of 2016 when disclosing an RWA flow chart becomes mandatory); and
- enhanced disclosure of RWA flow statements is a priority within the "Specific Opportunities for Ongoing Improvement".

In light of the limited available information for 2012 (and before), our work has focused on the years 2013 and 2014. The data available are sufficient for the robust estimation of results. The following table summarises the data set.

[64] In a very limited number of such cases, information on the effect of modelling adjustments was eventually obtained from footnotes or from references on the impact of modelling adjustments in the main text of the reports.

[65] The banks included in our sample correspond to major financial institutions from the UK, France, Germany, Netherlands, Belgium, Spain, Portugal, Italy, Norway, Sweden and Switzerland.

[66] All non-Euro values were converted to Euros using the end-of-period annual exchange rates, available from Eurostat.

[67] Similarly, less than half of the banks that were identified to have disclosed an RWA flow chart for 2013 had done so for 2012.

[68] The report can be accessed at http://www.financialstabilityboard.org/wp-content/uploads/r_130821a.pdf.

Table 4.3: Number of identified banks by country and year of disclosure

Country	Number of banks with annual 2014 data available	Number of banks with annual 2013 data available
United Kingdom	11	7
Netherlands	6	1
Belgium	5	0
France	4	1
Sweden	3	1
Portugal	3	0
Spain	2	1
Germany	2	2
Switzerland	2	2
Italy	1	1
Norway	1	0
Total	**40**	**16**

Source: Europe Economics research.

As an extension to our analysis, we also gathered additional data for European globally systemically important banks (G-SIBs). These typically have data available at a semi-annual frequency.[69] This resulted in a panel of 11 European G-SIBs with observations ranging from the second quarter of 2013 to the second quarter of 2015 (i.e. 55 observations in total).

Table 4.4: Number of identified G-SIBs by country

Country	Number of banks with 2013Q2-2015Q2 data available
United Kingdom	4
Netherlands	1
France	1
Sweden	1
Germany	1
Switzerland	2
Italy	1
Total	**11**

Source: Europe Economics research.

In light of the greater availability of annual model updates for the fiscal years 2013 and 2014, our quantitative analysis placed particular emphasis on the cross-section of these data. Nevertheless, our G-SIB panel enables us to verify our cross-sectional results within a longitudinal analytical framework while also accounting for unobserved differences across banks and across time (i.e. unobserved heterogeneity).

4.1.3 Performance indicators

Our data gathering process also focused on obtaining information on key bank performance indicators. These include:

- return on equity (ROE);
- weighted average cost of capital (WACC);[70]
- ratio of Tier 1 assets over total RWAs and its difference relative to the minimum regulatory requirement (i.e. Tier 1 headroom); and
- the regulatory leverage ratio for our sample of G-SIBs.

[69] The tendency was to publish such reports at Q1, Q2 and at the year-end — but not at Q3, impeding our ability to make a quarterly analysis.

[70] Information on banks' WACC was obtained from the Bloomberg database.

In the following table, we present the definition of the performance variables included in the analysis along with the source they were obtained from.

Table 4.5: Variable definitions and sources

Variable	Definition	Source
ROE	Ratio of Net Income over Total Equity	Annual and interim reports
WACC	The rate of return that the providers of a company's capital require, weighted according to the proportion each element (i.e. cost of equity, cost of debt and cost of preferred equity) bears to the total pool of capital.	Bloomberg database
Tier I headroom	Difference between Tier I ratio (i.e. the ratio of Tier I Assets over RWAs) and minimum Tier I ratio regulatory requirement. This was equal to 4 per cent in 2013 and 6 per cent in 2014.	Annual and interim Pillar 3 reports
Leverage ratio	The ratio of Tier I capital (capital measure) over the sum of on-balance sheet exposures, derivative exposures, securities financing transaction exposures and off-balance sheet items (exposure measure).	Annual and interim Pillar 3 reports

Source: Europe Economics research.

4.1.4 Banking supervision index

Last, our analysis also included an index capturing the effectiveness/involvement of the national supervisory bodies, as measured by the ability to take specific actions to prevent and correct problems. The nature of local banking supervision is a factor likely to influence the in-the-field deployment of IRB methodologies and, hence, the calculation and size of reported RWAs.[71] Moreover, as the values of this index vary by country, its inclusion allows us to account for country effects in the determination of modelling adjustments.

Accordingly, data on how banks are regulated and supervised were made publicly available by the World Bank,[72] were included in the analysis. The data were most recently updated in 2012, based upon a survey conducted in 2011.

The following three dimensions within the World Banks's data set were used to develop a time-invariant index:

- official supervisory power;
- independence of supervisory authority; and
- financial statement transparency.

As the above metrics are calculated in order to account for the 180 countries that were included in the original analysis, their values have been rescaled so as to account only for the countries included in our analysis. This rescaling process aimed at creating an ordinal index of banking supervision. An ordinal scale enables alternative regimes to be ordered in terms of involvement; this ordering is based on comparing the index scores of each country.

The primary purpose of the index scores is thus to rank the alternatives and it is not meant to be used for comparisons of magnitude (i.e. Italy with an "Official Supervisory Power" index score of six should not be

[71] See e.g. Ledo, M., (2011), "Towards more consistent, albeit diverse, risk-weighted assets across Banks", Estabilidad Financiera, No. 21, p. 49, Banco de España.

[72] See Barth, J., Caprio, G. and Levine, R. (2013), "Bank Regulation and Supervision in 180 Countries from 1999 to 2011." National Bureau of Economic Research Working Paper 18733. The raw data can be downloaded from: http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20345037~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html.

seen as having 'double' the power of a country scored at three in this sub-index).[73] The following table illustrates the constituent metrics of our index along with their original and rescaled value ranges.

Table 4.6: Supervisor authority index

Variable	Definition	Range	Rescaled Range
Official supervisory power	Whether the supervisory authorities have the ability to take specific actions to prevent and correct problems (a higher value is associated with greater power).	1-14	1-6
Independence of supervisory authority	The degree to which the supervisory authority is independent from the government and legally protected from the banking industry (a higher score is associated with greater independence from government and greater legal protection from the banking industry).	1-3	1-3
Financial statement transparency	The transparency of bank financial statements (a higher score is associated with more transparency).	1-6	1-4

Source: Europe Economics analysis, based upon the World Bank Regulation Index.

The rescaled values of the above metrics were summed and subsequently normalised in order to develop our index of banking supervision. Higher values reflect a state in which the involvement of the supervisor in assessing and controlling banking operations is expected to be greater. In contrast, lower values would suggest a 'looser' supervisory environment that could arguably be more conducive to strategic interventions in the calculation of RWAs. This index is not specific to prudential regulation. Therefore, whilst it offers a useful proxy, interpretation demands care.

The following table illustrates the distribution of index values across the countries included in our analysis. As noted above, these data were most recently updated in 2012 (i.e. likely reflective of some but not all of the changes that have been adopted since the onset of the financial crisis). However in some cases data were not available for at least some of the sub-divisions of the index from the most recent iteration of the survey. In these cases we used the most recent survey's results (the previous survey was conducted in 2007, i.e. pre-crisis). The countries affected are Sweden (no results from most recent survey) and the UK (only the score for the transparency of financial statements relates to the most recent iteration of the World Bank's work). Therefore any increase in, say, supervisory power, at least as measured by the index, in either Sweden or the UK post-crisis would not be reflected below. In our econometric analysis (described at 4.3.4 below) we also run a sensitivity whereby the index scores of the UK and Sweden are increased. This is described more fully in that sub-section.

[73] In any event, we tested both the original and rescaled indices in our econometric results, as presented in section 4.3.3. These remain unchanged using either index specification (i.e. rescaled versus original).

Table 4.7: Banking supervision index

Country	Official supervisory power	Independence of supervisory authority	Financial statement transparency	Composite banking supervision index
Scale	From 1 (lower relative supervisory power) to 6 (higher relative supervisory power)	From 1 (lower relative supervisory independence) to 3 (higher relative supervisory independence)	From 1(lower relative transparency) to 4 (higher relative transparency)	From 1 to 6
France	3	3	4	5
United Kingdom	1*	2*	3	1*
Spain	2	3	4	4
Italy	6	1	3	5
Norway	2	3	2	2
Sweden	2*	2*	3*	2*
Switzerland	4	2	4	5
Germany	4	1	3	3
Netherlands	3	2	1	1
Belgium	4	2	4	5
Portugal	5	3	4	6

Note: * signifies that data are not available from the 2012 data-gathering exercise, i.e. these scores relate to older surveys.
Source: Europe Economics elaboration of World Bank data set.

4.2 Descriptive statistics

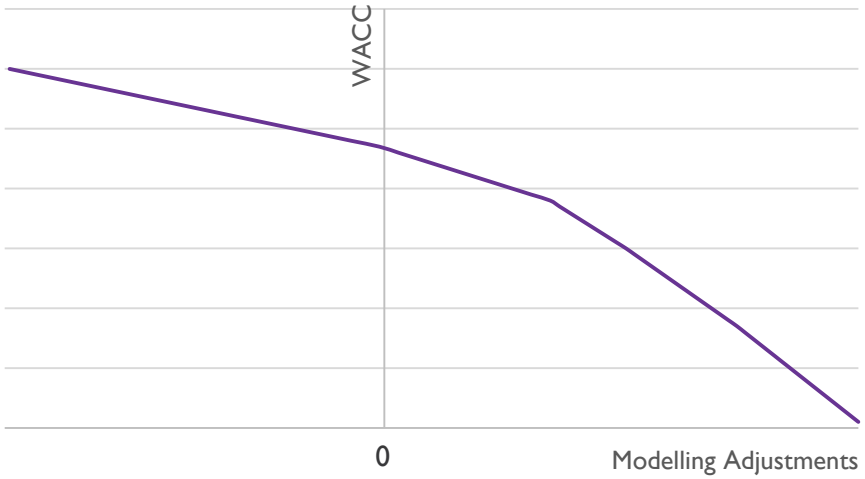
This section presents the variation in modelling adjustments compared to particular aspects of bank performance. When making comparisons between two variables it is difficult to draw robust conclusions. This is due to the fact that when accounting for observed variations in the scale of model adjustments based on only one variable (e.g. the cost of capital), one could be omitting the influence exerted by other variables (such as profitability or banking supervision).

As a result, we also employ econometric modelling, presented in the following section, allowing us to take into account the simultaneous influence exerted by other relevant variables. Nevertheless, the sets of graphs presented below can be helpful to detect potential trends and make preliminary observations.

For instance, as mentioned, a bank's cost of capital (i.e. Weighted Average Cost of Capital, WACC) has been portrayed as a potential driver of strategic modelling adjustments in the RWAs calculation.

According to the critics of the IRB method, one would expect to observe tactical modelling adjustments for capital-constrained banks (as captured by increasing WACC) either continuously, as a response to ongoing developments (see Figure 4.1), or abruptly, as a response to an adverse increase in the bank's cost of capital above a level perceived as too high (see Figure 4.2). In the first case, systematic tactical interventions in model assumptions and inputs reduce the overall size of RWAs. In the second case this occurs in the advent of a shock in the bank's WACC that calls for a reduction in the opportunity cost of holding excessive capital. The implications above are presented in stylised charts below. We begin with the arguments presented by the critics of IRB models, i.e. those who believe in strategically-motivated interventions in internal ratings-based models.

Figure 4.1: Movements of IRB modelling changes in response to increasing WACC



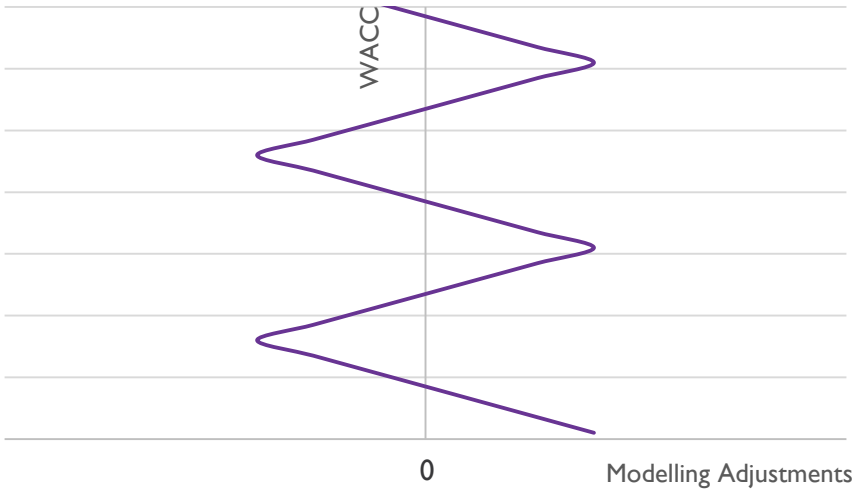
Source: Europe Economics.

Figure 4.2: Movements of IRB modelling changes in response to WACC increasing above some threshold

Source: Europe Economics.

On the other hand, according to the proponents of the IRB method, one would expect to observe no evidence of such a relationship (see Figure 4.3).

Figure 4.3: Movements of IRB modelling changes in response to increasing WACC



Source: Europe Economics.

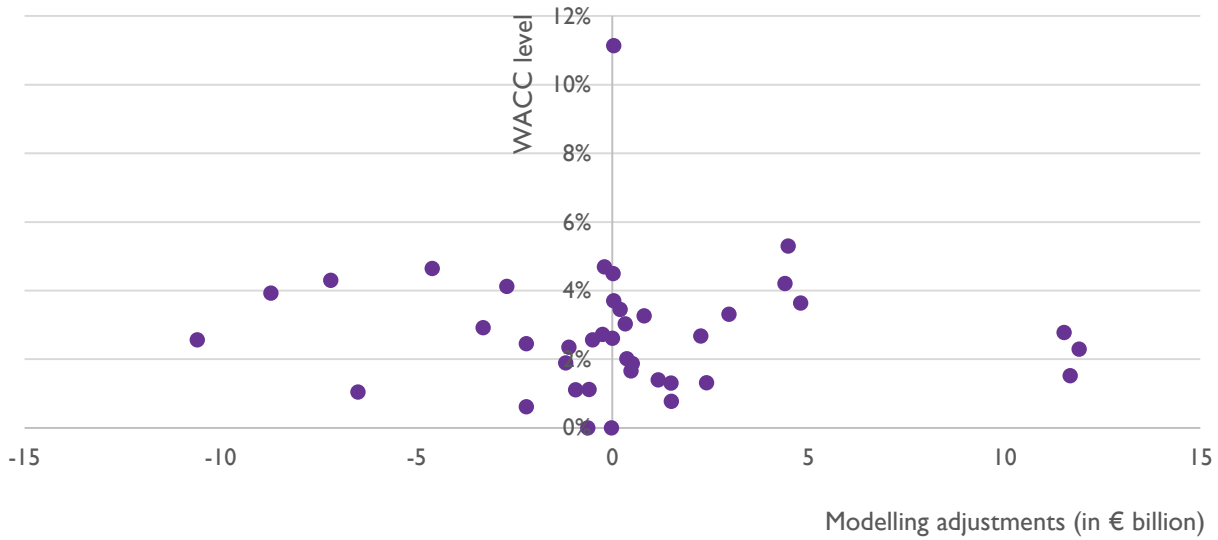
In light of the above stylized descriptions, we begin our analysis by first looking at how banks' RWA credit risk modelling adjustments vary with:

- their cost of capital (WACC);
- a measure of their profitability (ROE); and
- a measure of how capital-constrained they might be (Tier 1 headroom).

Subsequently, we repeat the analysis having normalised the observed modelling changes based on the amount of reported RWAs. This allows a clearer picture, since the size of modelling updates across banks is likely to be proportional to their overall size of RWAs.

The following graph presents the distribution of modelling adjustments across banks' different WACC levels. Negative values of modelling adjustments (i.e. a change in modelling resulting in a reduction in RWAs) as the WACC increases (or goes above a certain threshold) could be suggestive of tactical interferences in the calculation of RWAs. This would be a likely outcome for banks that view raising capital as particularly expensive and want to avoid raising relatively expensive Tier 1 capital. Figure 4.4 does not suggest such a pattern: higher levels of WACC do not correspond to an identifiable pattern of modelling adjustments.

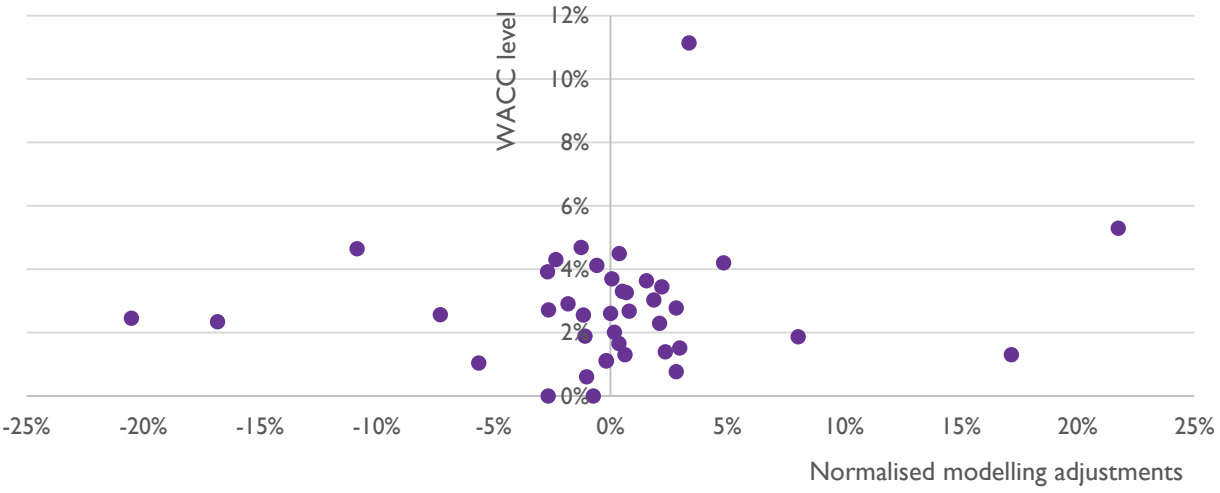
Figure 4.4: Modelling adjustments and WACC



Source: Europe Economics.

Now considering normalised changes (i.e. dividing the modelling adjustment with the scale of the bank's RWA), it can be observed that the dynamics presented in Figure 4.4 persist. If anything, normalised modelling adjustments appear to be positive, on average, and slightly clustered between 0 and 5 per cent of total RWAs. This result is hard to reconcile with widespread tactical interventions resulting from high capital costs.

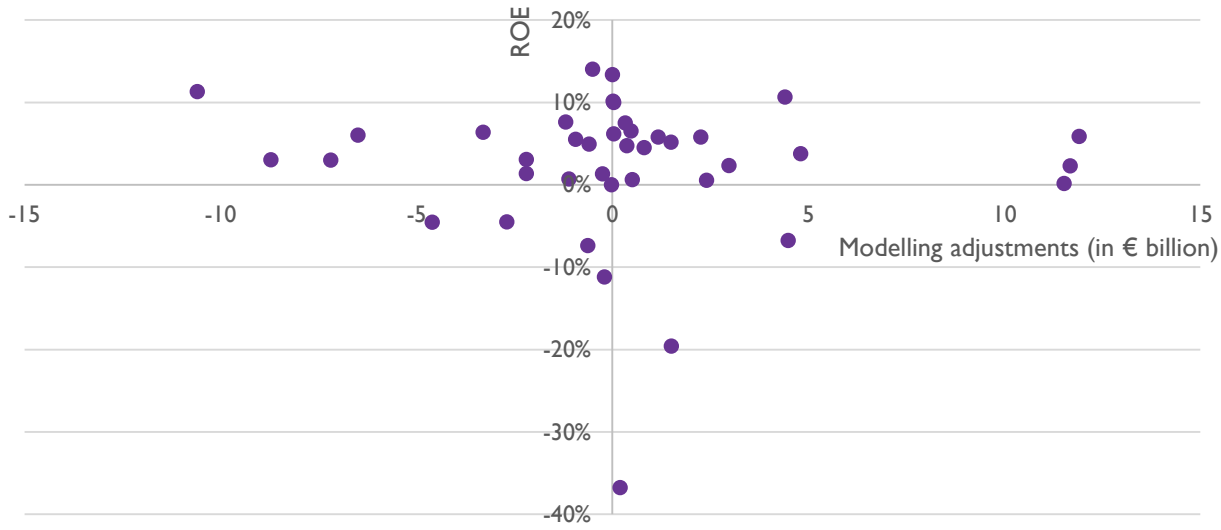
Figure 4.5: Normalised modelling adjustments and WACC



Source: Europe Economics.

We now turn to the impact of banks' profitability levels on modelling adjustments. The following graph presents the bivariate relationship between such changes and ROE. In general, banks with poor profitability could be incentivised to decrease their RWAs so that, in turn, Tier 1 capital could be reduced and substituted with cheaper capital.

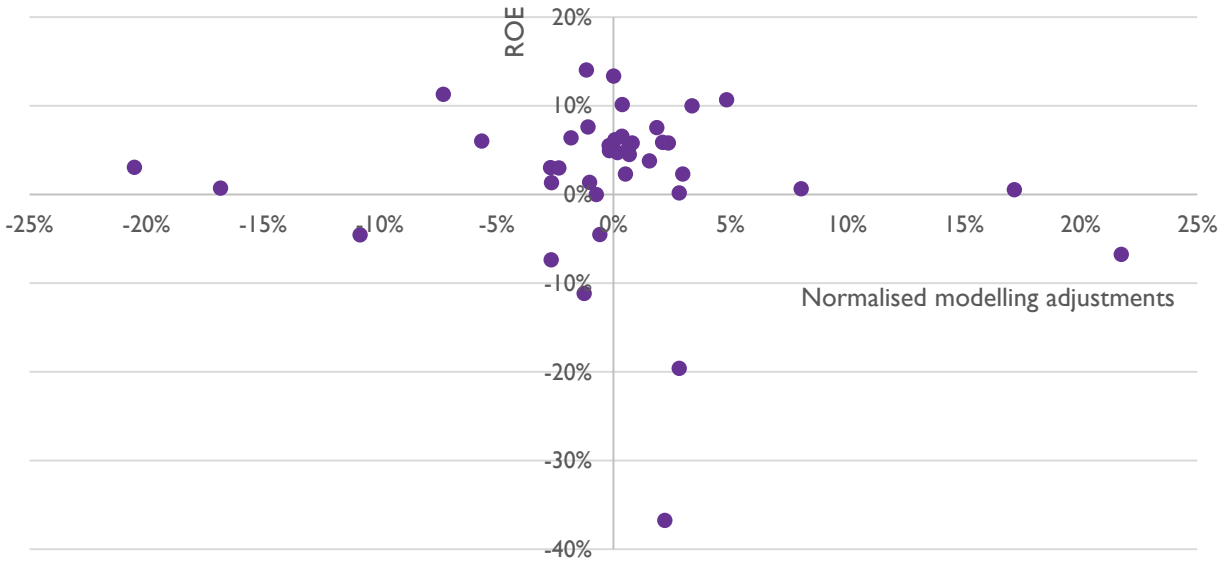
Figure 4.6: Model adjustments and ROE



Source: Europe Economics.

The distribution of normalised modelling changes is similar. Figure 4.6 shows that negative ROE and modelling adjustment values are not related in a systematic way, nor disproportionately large.

Figure 4.7: Normalised modelling adjustments and ROE



Source: Europe Economics.

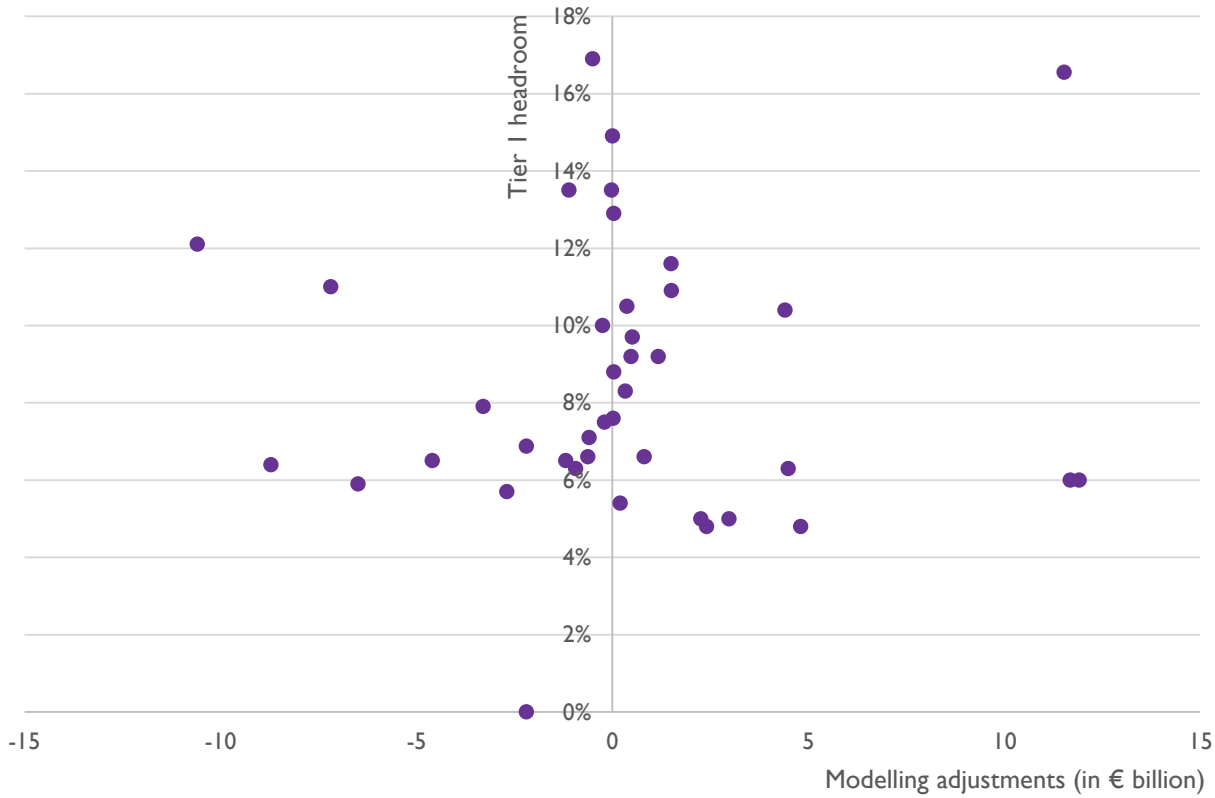
Last, we explore the postulated relationship between modelling adjustments and banks' financial health. More specifically, we explore the relationship between modelling changes and the difference between banks' Tier 1 ratios and minimum Tier 1 ratio requirements.[74] This difference would indicate the extent to which a bank is over- or under-capitalized.

In general, relatively under-capitalized banks might choose to reduce RWAs rather than increase additional prudential capital. This is due to the opportunity cost associated with Tier 1 holdings, as raising Tier 1 equity is more expensive than debt. Thus, such a bank might tactically adjust its modelling assumptions so as

[74] These amounted to six per cent in 2014.

to reduce the overall size of RWAs and, hence, its prudential capital requirements. Overall, Figure 4.8 does not support such a relationship, i.e. modelling adjustments to RWAs do not systematically become negative as headroom reduces.

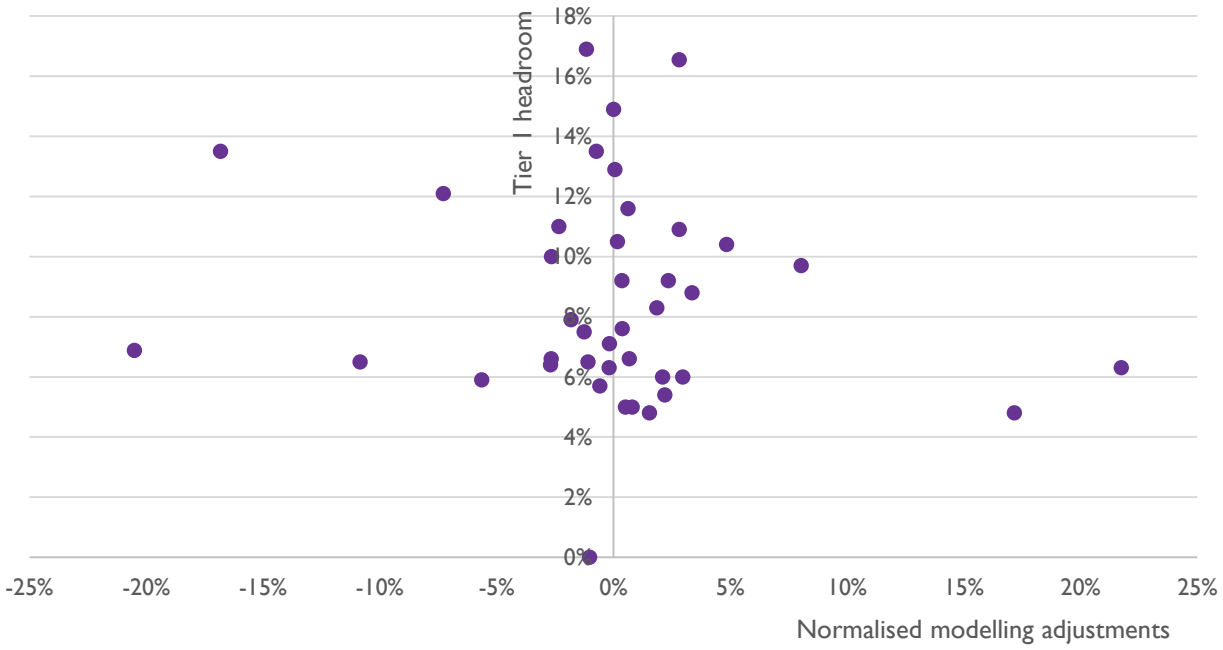
Figure 4.8: Modelling adjustments and Tier 1 headroom



Source: Europe Economics.

These relationships persist in the following figure portraying the relationship between normalised modelling changes and Tier 1 headroom.

Figure 4.9: Normalised modelling adjustments and Tier 1 headroom



Source: Europe Economics.

4.3 Econometric estimates

4.3.1 General approach to econometric modelling

The use of econometrics involves the application of mathematical and statistical methods to economic data, aimed at determining the impact of certain characteristics (independent variables) on an outcome (dependent variable). Specifically, econometrics allow us to infer the effect of a particular characteristic on the variable we wish to explain (modelling adjustments), while simultaneously accounting for the effect of any additional characteristics under consideration.

As highlighted in the previous section, exploring the interactions of two variables at a time does not allow us to draw robust conclusions. On the other hand, econometric analysis allows us to account for a number of factors that may be driving modelling adjustments. Ultimately, this level of analysis will allow us to corroborate (or negate) the findings of the previous section and explore whether they are supported within a multivariate analytical framework. By simultaneously taking into account all relevant variables, we will be able to investigate whether the presence of various performance measures has any statistically significant effects on modelling adjustments.

When estimating econometric models, there are two broad strategies that can be used: a 'general to specific' strategy and a 'specific to general' strategy. If the former strategy is adopted the econometrician starts with a model that contains 'many' potential explanatory variables and eliminates those that are not significant (either from a statistical or economic perspective) to develop a simpler model. The main objective is to obtain an estimated equation that is capable of 'explaining' the dependent variable at least as well as a more complex one but is preferred due to the fewer included explanatory factors. On the other hand, if the latter strategy is adopted, the econometrician starts with a simple model (usually one with a single explanatory variable) and adds variables until no additional explanatory power is provided.

There are theoretical reasons why it is usually preferable to adopt a 'general to specific' approach to econometric modelling. However, in practice this is not always possible as this strategy implies that the

number of included observations remains unchanged. However, if an observation is missing at the beginning of the procedure, potentially due to data unavailability on a specific variable, then that observation would not be used in the models.

Therefore, for our cross-sectional set of 40 annual bank observations we adopted a 'mixed' strategy. First, we developed basic OLS models including a limited number of explanatory variables that we would expect a priori to have an effect on modelling adjustments. Subsequently, we attempted to add additional explanatory variables.

Moreover, for the European G-SIBs we conducted panel data estimations. Such estimation methods are preferable in the presence of longitudinal data (i.e. data that vary across individuals and time) and allow us to capture variations across banks through time, while simultaneously accounting for any influence exerted by other external factors.

4.3.2 Sample Size

We have described our data set already, at 4.1.2. We have sufficient data for robust estimation in both our cross-section of all banks for which we have data, and our longitudinal analysis of the G-SIBs.

4.3.3 Robustness tests

In order to assess the overall explanatory power of each estimated model, we used the R-squared statistic. The R-squared is a statistical measure, expressed in percentage form, which captures the goodness of fit of a specified model. The goodness of fit describes the discrepancy between the observed values and the predicted values under the model, i.e. how well the model fits the data. Therefore, an R-squared of 100 per cent suggests that the regression line perfectly fits the data.

However, the R-squared increases with the number of variables included in the estimation. This generates a drawback to its use, where one might keep adding variables ("kitchen sink" regression) to increase the R-squared value. This leads to the alternative approach of looking at the adjusted R-squared which imposes a "penalty" as extra variables, which do not offer any additional explanatory power, are included in the model.

Moreover, an F-test was conducted enabling us to assess the probability that all included variables jointly offer no significant explanatory power.[75] The determination of the contribution of each additional variable to the overall explanatory power of the model was achieved using the Akaike Information Criterion and the Schwarz-Bayes Criterion.[76] As a result, the final models included specifications exhibiting the lowest values of the aforementioned criteria.

Lastly, a number of diagnostic tests were employed in order to check whether including additional variables had an impact on the extent to which the estimated model satisfied the assumptions of the chosen regression specification.[77] The results of these tests were satisfactory. The detailed outputs of these robustness tests can be found in the table notes of the Technical Appendix.

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[75] A probability below 0.10 would strongly suggest that the adjusted R-squared is a reliable indicator.

[76] The Akaike Information Criterion and the Schwarz-Bayes Criterion allow non-nested models (i.e. models that may have entirely different sets of explanatory variables) to be compared and provide information on the extent to which each model fits the data.

[77] The diagnostic tests included testing for multicollinearity (using collin in Stata). This allows us to compute the average Variance Inflation Factor (VIF) for each model, while making sure that each variable's VIF score is below 10. We also account for correct model specification (using ovtest in Stata). This allows us to compute the Prob (F-stat) for the Ramsey RESET test. A value above 0.10 would suggest that the model is not exposed to specification errors. Lastly, to account for heteroscedasticity, all models were estimated using White heteroscedasticity-consistent standard errors and covariance (using robust in Stata). Lastly, for panel estimations, we also account for residual autocorrelation (using xtserial in Stata).

4.3.4 Econometric results

We present in this section the results of our econometric models. Our univariate analysis in Section 4.2 indicated that although mainly positive, some modelling changes, relative to RWAs, can be high. Accordingly, the purpose of this multivariate analysis is to determine whether these are significantly related to bank-specific performance measures and may thus be regarded as intrinsically suspicious or not. In particular, we test the relationships between the following set of variables:

- modelling adjustments at levels or as a share of total RWAs;
- the return on equity;
- the weighted average cost of capital;
- the difference between Tier 1 ratio and minimum requirement (i.e. Tier 1 headroom);
- the regulatory leverage ratio; and
- an index of banking supervision.

The first three models contain a cross-section of 38 banks' data for the full year 2014.[78] These models (M1–M3) look at whether banks' reported modelling adjustments can be explained by our set of explanatory variables. Accordingly, the first three tables present the dependent variable in the top rows, followed by the explanatory variables in the leftmost column of the lower rows; the impact that the explanatory variables have in the middle column; and the p-value of each coefficient estimate in the last column.

The p-value is the measure used to determine whether an explanatory variable has a statistically significant impact on the chosen dependent variable. Generally, the margins of significance are attained when p-values drop below 0.1; significance is considerably stronger when p-values drop below 0.01. On the other hand, a p-value above 0.1 suggests the absence of a significant identifiable relationship.

Estimation results for M1 are presented first: this model includes the return on equity, Tier 1 headroom, the WACC and the index of banking supervision. The table below clearly illustrates that the included explanatory variables do not explain the observed variation in banks' modelling changes.[79] The model has also been tested for parameter stability and issues such as multi-collinearity with satisfactory results.[80] Further details on the estimation of all models are contained within the Appendix.

Table 4.8: Estimation results for Model 1 (M1)

Dependent variable		
Modelling changes		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Return on equity	Statistically indistinguishable from zero	0.51
Tier 1 headroom	Statistically indistinguishable from zero	0.84
Weighted Average Cost of Capital	Statistically indistinguishable from zero	0.55
Index of supervisory power	Statistically indistinguishable from zero	0.81

Source: Europe Economics estimates.

Subsequently, we test to see whether there is a significant difference in the coefficient estimates in different sub-samples corresponding to high/low values of our performance indicators (i.e. a structural break).[81] The objective here is to test the hypothesis that it is only at extreme values that any 'suspicious' relationship between the modelling adjustments and explanatory variables become apparent. If this held true, the statistical signal indicating such a relationship could be drowned out when considering the entire sample. These breakpoints relate to:

[78] Two observations were dropped as information on their WACC not available on Bloomberg.
[79] All p-values are considerably higher than 0.1 which implies no statistical significance.
[80] Multi-collinearity refers to the issue where some of the explanatory variables may be a linear function of each other; this issue needs to be avoided in order to ensure that no violations to regression assumptions are present.
[81] To do so we perform a Chow breakpoint test which assesses the validity of the null hypothesis of stability in the estimates across regimes.

- WACC levels above average or within the top decile (i.e. when capital is more dear);
- ROE levels below average or within the bottom decile; and
- Tier 1 headroom below average or within the bottom decile

Overall, our results suggest the absence of such breaks in our estimations.[82]

In M2 we re-estimate M1 while adjusting our dependent variable for the size of reported RWAs. However, this does not alter the results as all variables are still not capable of explaining variations in the normalised modelling changes between different banks. Similarly, our breakpoint tests suggest the absence of different regimes within the estimates.

Table 4.9: Estimation results for Model 2 (M2)

Dependent variable		
Normalised modelling changes		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Return on equity	Statistically indistinguishable from zero	0.88
Tier 1 headroom	Statistically indistinguishable from zero	0.43
Weighted Average Cost of Capital	Statistically indistinguishable from zero	0.49
Index of banking supervision	Statistically indistinguishable from zero	0.14

Source: Europe Economics estimates.

In the following model (M3), we look at the potential influence of year over year changes in ROE, Tier 1 headroom and WACC on modelling changes. This allows us to examine whether annual changes in modelling adjustments are affected by annual changes in performance measures. However, our estimation results indicate that none of these variables appears to significantly explain variations in modelling changes across the banks in our sample.

Table 4.10: Estimation results for Model 3 (M3)

Dependent variable		
Modelling changes		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Δ (return on equity)	Statistically indistinguishable from zero	0.91
Δ (Tier 1 headroom)	Statistically indistinguishable from zero	0.17
Δ (weighted average cost of capital)	Statistically indistinguishable from zero	0.80
Index of banking supervision	Statistically indistinguishable from zero	0.94

Source: Europe Economics estimates.

In M4 and M5 we include in this cross-sectional analysis our 2013 modelling adjustment data. In so doing we are effectively treating observations from both years as independent. This allows us to look at potential breakpoints in the distribution of RWAs through time, while also increasing our estimation sample.[83] It can be observed that the insignificant effect of all explanatory variables persists, and the reported outputs of the breakpoint tests indicate the absence of structural breaks.

Table 4.11: Estimation results for Model 4 (M4)

Dependent variable		
Modelling changes		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Return on equity	Statistically indistinguishable from zero	0.58
Tier 1 headroom	Statistically indistinguishable from zero	0.53
Weighted Average Cost of Capital	Statistically indistinguishable from zero	0.57
Index of supervisory power	Statistically indistinguishable from zero	0.35

Source: Europe Economics estimates.

[82] The outputs of the breakpoint tests can be found in the Appendix.

[83] In this model, our sample size increases to 54 observations as compared to the 40 observations in M1-M3.

Table 4.12: Estimation results for Model 5 (M5)

Dependent variable		
Normalised modelling changes		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Return on equity	Statistically indistinguishable from zero	0.98
Tier 1 headroom	Statistically indistinguishable from zero	0.16
Weighted Average Cost of Capital	Statistically indistinguishable from zero	0.31
Index of banking supervision	Statistically indistinguishable from zero	0.24

Source: Europe Economics estimates.

In models M1–M5 the impact of the banking supervision index (described at 4.1.4) has been statistically indistinguishable from zero. As we have noted, the data used in this index for the UK and Sweden are pre-crisis, and could therefore not account sufficiently for any recent changes in approach. We created an adjusted composite banking supervision index such that, where the scores were from a previous survey, we adjusted the individual domain scores for these two countries to the higher of the past survey score and the average for the other countries in the population. This created an adjusted index where the UK's score increased from one to four, and Sweden's from two to four. We then re-ran models M1–M5 with the index revised in this way: the results were as before, i.e. the impact of the banking supervision index remained statistically indistinguishable from zero.

The next two models (M6 and M7) relate to our panel data estimations across European G-SIBs. These estimations also include banks' reported regulatory leverage ratio as an independent variable.[84] European G-SIBs consistently report regulatory leverage figures and thus allow us to capture its effect on RWA modelling adjustments. In M6 the dependent variable is the modelling changes occurring at a semi-annual frequency. In M7 the dependent variable is adjusted by RWA size. The rationale behind exploring this different form is to obtain a normalisation of modelling changes' magnitude.

As the following two tables show, none of the independent variables of the reported model specifications have a statistically significant effect on the modelling changes, either at their level form or adjusted for RWA size. Thus, even by introducing a time horizon into the analysis the independent variables are still not explaining the variation in modelling changes across banks.

Table 4.13: Estimation results for Model 6 (M6)

Dependent variable		
Modelling changes (semi-annual)		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Return on equity	Statistically indistinguishable from zero	0.96
Leverage ratio	Statistically indistinguishable from zero	0.78
Tier 1 headroom	Statistically indistinguishable from zero	0.75
Weighted Average Cost of Capital	Statistically indistinguishable from zero	0.12

Source: Europe Economics estimates.

Table 4.14: Estimation results for Model 7 (M7)

Dependent variable		
Normalised modelling changes (semi-annual)		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Return on equity	Statistically indistinguishable from zero	0.91
Leverage ratio	Statistically indistinguishable from zero	0.88
Tier 1 headroom	Statistically indistinguishable from zero	0.81
Weighted Average Cost of Capital	Statistically indistinguishable from zero	0.18

Source: Europe Economics estimates.

[84] The leverage ratio has not been considered in previous stages of the analysis as it was not reported consistently among the banks included in the wider sample.

Lastly, in Model 8 (M8) we aim to verify the above results by following an alternative analytical avenue. More specifically, for our annual cross-section of data we distinguish, where available, the reported value of RWAs between RWAs calculated using IRB methods and RWAs calculated using standardized methods.[85] A ratio of IRB-RWAs over standardized-RWAs is subsequently constructed indicating a bank's IRB intensity in the calculation of its RWAs. The ratio is then included as an independent variable in an estimation where the dependent variable corresponds to the ratio of RWAs to total assets (i.e. RWA density).

Overall, the determinants of RWA density have been the focus of the vast majority of empirical studies aiming to identify the sources of variability in RWAs across banks and jurisdictions.[86] These studies present mixed conclusions and offer different accounts of factors that can be expected to drive variation in RWAs, even in the absence of strategic adjustments. The breadth of variables that can logically be expected to have a significant effect on RWA density distorts the causal link that one would want to establish when studying incentives for strategic IRB modelling decisions.

In light of the above, the approach we have implemented so far is more granular in nature as it explores the more isolated causal links between incentives to implement strategic behaviour and their materialisation through IRB modelling adjustments.

Therefore, the interpretation of M8 is less straightforward than in the other models, i.e. there are various explanations as to the inferences to be drawn from variation in RWA density. A significantly negative effect could indicate the potential presence of interventions occurring in internal models so as to decrease RWAs and, hence, RWA density. However, this could also simply be indicative of consistently lower RWA density for IRB banks compared to banks using the standardised approach — which would accord with expectations (e.g. that IRB banks are larger and more complex, and more likely to be involved in higher risk activities).

It can be observed in M8, that IRB-intensity does not significantly affect RWA density, although there is a positive and marginally significant effect that appears to be driven by a bank's cost of capital. The weighted average cost of capital is the minimum expected return that investors require for financing a company either through equity, or through debt. This means that, when calculated, the WACC will produce a rate equivalent with the current level of risk present in a company's activities. Thus, the observed effect suggests a positive relation between overall bank-risk and RWAs which is to be expected assuming RWAs are calculated so as to reflect a bank's risk exposure. Nevertheless, the marginal statistical significance of its coefficient estimate reinforces the view that the WACC is a poor proxy for overall bank risk.

Table 4.15: Estimation results for Model 8 (M8)

Dependent variable		
RWA density		
Explanatory variables	**Impact on the dependent variable**	**P-value**
Return on equity	Statistically indistinguishable to zero	0.76
IRB-intensity	Statistically indistinguishable to zero	0.79
Weighted average cost of capital	Positive and statistically different from zero	0.08
Tier 1 headroom	Statistically indistinguishable to zero	0.93
Index of banking supervision	Statistically indistinguishable to zero	0.27

Source: Europe Economics estimates.

As identified previously, the data used in the banking supervision index for the UK and Sweden are old. Using the process described previously we again re-ran model M8 with the revised index. This time the IRB-intensity variable became statistically significant, albeit only at the 10 per cent confidence level. As we have noted, we find M8 a crude tool for examining the topics of interest in this study.

[85] A total of 30 banks was included in this estimation due to data unavailability with regards to the size of RWAs that were calculated using internal models.

[86] See for example Vallascas and Haggendorff (2013), Behn et al. (2014), Bruno et al. (2014) and Carr (2015).

4.4 Conclusions

We have looked carefully for links between those variables identified in the literature as potential reasons for the gaming of Internal Ratings-Based (IRB) models — such as having a high cost of capital and being capital constrained — and the observed variation in RWA modelling changes.

We have found no evidence for such links. Based on the results of the models presented above we have found that none of the variables identified in the literature as potential reasons for the gaming of IRB models explain the observed variation in RWA modelling changes.

This analysis does not disprove the thought that a bank might engage in such activities — but the finding is wholly inconsistent with the hypothesis that this is common practice. Based on what we have observed, RWA modelling adjustments are exogenous to bank-specific performance measures. This means that the argument put forward by critics of the IRB approach is at present unproven. Supervisory attention on significant variations in model inputs may, in time, build such a case. Pillar 3 disclosures will help identify the reasons behind changes in RWAs.

Supervisors looking at unexplained variation in models should also examine how they are implemented in differences in implementation between different national jurisdictions. Equally, increased harmonisation across the Single Market would be welcome. But since our work indicates that the system is far from broken, more drastic action around the IRB at this point looks unjustified.

Technical Appendix

Europe Economics

5 Technical Appendix: Econometrics

5.1 Description of estimated equations

As noted in the main body of this report, the use of econometrics involves the application of mathematical and statistical methods to economic data, aimed at determining the impact of certain characteristics (independent variables) on an outcome (the dependent variable). Specifically, the use of econometrics allows us to infer the effect of a particular characteristic on the variable we wish to explain (in this case, modelling adjustments), by simultaneously taking into account all other relevant variables.

In this study we adopted two econometric techniques in order to identify the determinants of credit risk modelling adjustments in the calculation of RWAs. These are:

- cross-sectional regressions; and
- panel estimations.

A cross-sectional regression is a type of estimation in which the explained and explanatory variables are associated with one period or point in time. The estimated equation is of the following form:

$$m_i = \alpha_i + X_i\beta + \varepsilon_i$$

where m_i is the dependent variable (i.e. modelling adjustments or normalised modelling adjustments) for firm i, X_i is a set of explanatory variables (i.e. performance indicators, banking supervision index) for firm i and ε_i is the error term.

In contrast, panel data estimations allow for data to vary both across individuals and time. They have the advantage of allowing us to account for the effect of variables that may be important explanatory factors but for which data is not observable, i.e. unobserved heterogeneity. Specifically, unobserved heterogeneity in a panel framework could be dealt with through the use of particular estimation techniques (in our case fixed effects estimators) which are designed with the precise goal of controlling for idiosyncratic features that are not directly observable in the data. In particular a panel data estimated equation is of the following form:

$$m_{i,t} = \alpha_i + X_{i,t}\beta + \varepsilon_{i,t}$$

where m_i is the dependent variable for firm i at time t, X_i is a set of explanatory variables for firm i at time t and $\varepsilon_{i,t}$ is the error term.

5.2 Interpreting estimation results

To interpret the regression results presented in the tables below, a little background knowledge of econometrics and statistics is required. In this section, we seek to provide the necessary knowledge to understand the discussion that follows.

The tables below consist of the following columns:

Explanatory variables	*Coef.*	*P-value*

The "Explanatory variables" column contains the explanatory variables of the regression model. Explanatory variables are those factors which we believe might have an impact on the dependent variable.

The "Coef" column shows the impact of the explanatory variable on the dependent variable. A positive value for the coefficient indicates that an increase in the value of the variable increased the dependent variable and vice versa.

It is important to note that not all variables have a statistically significant influence on the dependent variable. Statisticians and econometricians use significance tests to determine whether or not a particular explanatory variable has an impact on the dependent variable. This is determined by drawing inferences based on the "P-value" column.

In particular, the p-value is the measure used to determine whether an explanatory variable has a statistically significant impact on the chosen dependent variable. Generally, the margins of significance are attained when p-values drop below 0.1; significance is considerably stronger when p-values drop below 0.01. On the other hand, a p-value above 0.1 suggests the absence of a significantly identifiable relationship exists.

Given the potential presence of heteroscedasticity,[87] the standard errors on which the statistical significance tests are based are calculated using White heteroscedasticity-consistent standard errors and covariance.

5.3 Presentation of estimation results

In this section, our estimation results are presented. Initially, our model specifications for our cross-sectional regressions are presented along with the outputs of our structural point tests. Subsequently, we present our panel data estimations on the G-SIBs. Lastly, the cross-sectional model in which the dependent variable is RWA density (i.e. Model 8) is presented.

5.3.1 Cross-sectional estimations

Table 5.1: Estimation results for Model 1 (M1)

Dependent variable		
Modelling changes		
Explanatory variables	**Coef.**	**P-value**
Return on equity	-3.45	0.51
Tier 1 headroom	5.70	0.84
Weighted Average Cost of Capital	-16.57	0.55
Index of supervisory power	0.09	0.81

Note: R-squared: 1.11 per cent; AIC: 6.17; BIC: 6.39; mean VIF: 1.28; Prob (F-stat): 0.983; Ramsey RESET test Prob (F-stat): 0.539.

The following table presents the output of our breakpoint test. The P-value indicates the probability of accepting the null hypothesis of stability in the estimates, i.e. there is no break in the series, which would be the case if it is greater than 0.10. It can be observed that the null hypothesis is accepted across all tested regimes.

Table 5.2: Breakpoint tests for Model 1 (M1)

Variable	**P-value for average**	**P-value for decile**
ROE	0.35	0.85
Tier 1 headroom	0.25	0.84
WACC	0.45	0.86

Source: Europe Economics estimates.

[87] In statistics, a collection of random variables is heteroscedastic if there are sub-populations that have different variabilities from others. Variability could be quantified by the variance or any other measure of statistical dispersion. Regression analysis using heteroscedastic data still provides an unbiased estimate for the relationship between the predictor variable and the outcome, but standard errors and inferences obtained from data analysis are suspect.

Table 5.3: Estimation results for Model 2 (M2)

Dependent variable		
Normalised modelling changes		
Explanatory variables	**Coef.**	**P-value**
Return on equity	-0.01	0.88
Tier 1 headroom	-0.21	0.43
Weighted Average Cost of Capital	0.36	0.49
Index of banking supervision	0.01	0.14

Note: R-squared: 0.9 per cent; AIC: -2.34; BIC: -2.13; mean VIF: 1.65; Prob (F-stat): 0.37; Ramsey RESET test Prob (F-stat): 0.908.

Table 5.4: Breakpoint tests for Model 2 (M2)

Variable	**P-value for average**	**P-value for decile**
ROE	073	0.98
Tier 1 headroom	0.96	0.39
WACC	0.97	0.99

Source: Europe Economics estimates.

Table 5.5: Estimation results for Model 3 (M3)

Dependent variable		
Modelling changes		
Explanatory variables	**Coef.**	**P-value**
Δ(return on equity)	0.54	0.91
Δ(Tier 1 headroom)	-31.76	0.17
Δ(weighted average cost of capital)	19.39	0.80
Index of banking supervision	0.03	0.94

Note: R-squared: 6.37 per cent; AIC: 6.12; BIC: 6.34; mean VIF: 1.47; Prob (F-stat): 0.692; Ramsey RESET test Prob (F-stat): 0.409.

Table 5.6: Estimation results for Model 4 (M4)

Dependent variable		
Modelling changes		
Explanatory variables	**Coef.**	**P-value**
Return on equity	-3.02	0.58
Tier 1 headroom	-11.86	0.53
Weighted Average Cost of Capital	-15.66	0.57
Index of supervisory power	-0.33	0.35

Note: R-squared: 2.95 per cent; AIC: 6.13; BIC: 6.31; mean VIF: 1.16; Prob (F-stat): 0.827; Ramsey RESET test Prob (F-stat): 0.249.

Table 5.7: Breakpoint tests for Model 4 (M4)

Variable	**P-value for average**	**P-value for decile**
ROE	0.53	0.79
Tier 1 headroom	0.52	0.86
WACC	0.55	0.38
Year 2013	0.46	-

Source: Europe Economics estimates.

Table 5.8: Estimation results for Model 5 (M5)

Dependent variable		
Normalised modelling changes		
Explanatory variables	**Coef.**	**P-value**
Return on equity	-0.01	0.98
Tier 1 headroom	-0.26	0.16
Weighted Average Cost of Capital	0.47	0.31
Index of banking supervision	0.01	0.24

Note: R-squared: 7.87 per cent; AIC: -2.59; BIC: -2.41; mean VIF: 1.55; Prob (F-stat): 0.393; Ramsey RESET test Prob (F-stat): 0.739.

Table 5.9: Breakpoint tests for Model 5 (M5)

Variable	P-value for average	P-value for decile
ROE	0.18	0.96
Tier 1 headroom	0.88	0.30
WACC	0.90	0.85
Year 2013	0.82	

Source: Europe Economics estimates.

5.3.2 Panel data estimations

Table 5.10: Estimation results for Model 6 (M6)

Dependent variable		
Modelling changes (semi-annual)		
Explanatory variables	**Coef.**	**P-value**
Return on equity	0.01	0.96
Leverage ratio	-8.79	0.78
Tier 1 headroom	13.06	0.75
Weighted Average Cost of Capital	-26.63	0.12

Note: R-squared: 11.57 per cent; Prob (F-stat): 0.166; Serial correlation Prob (F-stat): 0.531.

Table 5.11: Estimation results for Model 7 (M7)

Dependent variable		
Normalised modelling changes (semi-annual)		
Explanatory variables	**Coef.**	**P-value**
Return on equity	-0.01	0.91
Leverage ratio	0.84	0.88
Tier 1 headroom	-0.43	0.81
Weighted Average Cost of Capital	0.01	0.18

Note: R-squared: 6.82 per cent; Prob (F-stat): 0.024; Serial correlation Prob (F-stat): 0.523.

5.3.3 RWA density cross-sectional estimations

Table 5.12: Estimation results for Model 8 (M8)

Dependent variable		
RWA density		
Explanatory variables	**Coef.**	**P-value**
Return on equity	-0.14	0.76
IRB-intensity	-0.01	0.79
Weighted average cost of capital	5.66	0.08
Tier 1 headroom	0.12	0.93
Index of banking supervision	0.03	0.27

Note: R-squared: 19.84 per cent; AIC: -0.47; BIC: -0.19; mean VIF: 2.80; Prob (F-stat): 0.344; Ramsey RESET test Prob (F-stat): 0.743.