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**Model risk management**  
Building supervisory confidence

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**REGULATORY  
STRATEGY**

The model is the logical embodiment of the half-truth, "There is nothing new under the sun"; the rules for applying it cannot neglect the equally significant half-truth, "History never repeats itself."

**Milton Friedman, *Essays in Positive Economics*, The University of Chicago Press, 1953**

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# Introduction

This report sets out our views and experience on how financial services firms can apply practical model risk management to build supervisory confidence in models and modeling. It draws on the experience and expertise of Deloitte model risk management teams worldwide, working in those areas that are of greatest current concern to supervisors across financial services.

How far should regulators rely on the regulated? There are few areas of regulation and supervision that pose this question more urgently than the use of models. Recent regulation has attempted to accommodate, or even encourage, the use of models, while setting strict standards for model risk management. This balance is struck in practical policy and front-line supervision, and the overall direction of travel in many jurisdictions has been favorable for model use: **in our view, firms that implement model risk management frameworks that satisfy both regulatory requirements and supervisors' practical concerns, and operate at a commercially-viable cost, are well-positioned to find a supportive policy environment for the use of models.**

Models serve many important strategic purposes for financial services firms. At best, these capabilities can be harnessed to make regulation and supervision more targeted and more effective. For example, models can provide:

- greater insight into business risks and strategy; and
- a better fit to complex risks and diversified businesses than standardized formulas, resulting in more efficient and appropriate allocation of capital.

On the other hand, model use poses many risks which supervisors must, at least, recognize. Users of models, therefore, simultaneously face a broadly supportive policy environment, but increasing supervisory concern and scrutiny as to the use of models in practice.

**In this report we discuss current trends in the supervision of model risk management in financial services firms. Based on our expertise and experience, we explore those areas of model risk management that we consider to be of the greatest current concern to supervisors, and how firms can respond to supervisors' concerns to build confidence in their models and modeling.**

**Our experience is that supervisors' assessments of individual firms' effectiveness will greatly influence their approach. Supervisors will neither approve nor place reliance on the firm's strategic and operational use of a model, including for risk assessment and capital planning, unless satisfied with a firm's model risk management.**

**In particular, we expect supervisors to attach the most importance to the board's oversight and challenge of the model, to effective, independent model validation, and to the organizational status of model risk management which enables these.**

Core to supervisors' concerns are:

- **effective governance** of models by the board, senior management and the risk management function, including:
  - board understanding of the firm's use of models, and in particular the limitations of models and their results;
  - individual board member and senior management accountability for the model and model risk;

- strength and independence of model validation; and
- challenge to model builders, including assumptions and parameters, calibrations, and the risk of "group think".
- **internal organization** that provides a model risk management function with sufficient formal influence, for example through direct reporting lines to the board, and appropriate allocation of responsibilities;
- **model change and model development incentives**, in particular whether there are inappropriate commercial pressures on the model builders and how these might translate into erosion of real capital cover;
- **unidentified use** of material models, or use of models in ways for which they were not intended; and
- **systemic risks**, including systematized approaches or errors (including through "herding" around common approaches) that may lead to destabilizing effects in a crisis.

In practice, the approach in regulation and levels of supervisory enthusiasm for models differ across jurisdictions and sectors and, to some extent, between supervisory policy technicians and supervisors on the "front line". In this report we consider the range of approaches to these questions globally and across financial services. This report draws on the input and insight of colleagues across Deloitte's international network. The Center for Regulatory Strategy is grateful to all of the Deloitte practitioners who provided input into this report.



Regulations issued since the global financial crisis have formalized the concept of “model risk management”. **Supervisors expect all firms using models to put in place certain common core model risk management components, implemented appropriately for their model use environment.** While there are many ways to describe these, we use the framework set out in Figure A, which is consistent with the Supervisory Guidance on Model Risk Management (SR 11-7) issued by the Board of Governors of the Federal Reserve System and Office of the Comptroller of the Currency, and with European Central Bank (ECB) expectations.

Figure A



# Regulation and supervision of models

## Why are supervisors concerned about models?

Models present opportunities for regulators, but also pose associated challenges. On the one hand, models are valuable commercial tools and harnessing their analytical capabilities presents opportunities to improve regulation and supervision. On the other hand, as we discuss in this report, regulators also see the misunderstanding or misuse of models (both internally-developed and vendor models) posing substantial risks to firms, their customers and the regulators' objectives, including maintaining financial stability.

Supervisors do not expect models to be entirely accurate all of the time;<sup>1</sup> rather they expect the model output to be underpinned by a sufficient degree of statistical confidence. As a tool to estimate what may occur in the real world, a model will never be error-free. Supervisory guidance accordingly identifies two principal ways in which models can pose material risk to financial services firms:<sup>2</sup>

1. **Models may be manipulated, misunderstood or misused, taking account of the results they produce, leading to unexpected losses for the firm misusing the model.**
2. **Inaccurate model results may lead to unexpected losses for the firm using the model. All models will fail to represent the "state of the world" to some extent.**

Regulators' approaches to models vary widely (see Appendix), which we consider broadly reflects differing views amongst regulators as to the risks posed by increasing complexity, how far reliance should be placed on firms, and the degree of enhanced insight into businesses and risks that models can provide when applied effectively.

In recent history there has been a great deal of public questioning on the risks and incentives created by models in the financial services industry. A number of high-profile model and model risk governance failures placed model risk in sharp focus during and in the aftermath of the financial crisis.<sup>3</sup> However, model risk continues to crystallize and to be of concern to supervisors. Some recent examples include:

- Immediately following the application of the Packed Retail and Insurance-based Investment Products (PRIIPs) regulation in 2018, firms and regulators<sup>4</sup> expressed concern that, in some cases, the standardized calculation of "performance scenarios" using fixed data periods was producing projected performance guidance that was too optimistic and potentially misleading to consumers.

- The UK Financial Conduct Authority (FCA) identified statistical bias in models as a source of potential consumer detriment in its 2015 Thematic Review<sup>5</sup> of product development and governance for structured products, stating *"The net effect of these issues is the production of modelling simulations that may not accurately reflect potential market scenarios and could lead to more optimistic estimates of potential product performance."*
- Supervisors are particularly concerned about the observed tendency for model calibrations to decline over time as firms develop their models.<sup>6</sup> One explanation for this trend would be imbalanced incentives, whereby firms are more likely to expend model development resource on developments that decrease capital requirements, although reductions in calibrations are not always inappropriate per se, for example, where data or methodology improvements mean that compensating conservatism can be removed.

1 For example, SR 11-7 notes that "[a]ll models have some degree of uncertainty and inaccuracy because they are by definition imperfect representations of reality."

2 We have defined these principles broadly here, following more specific definitions of "model risk" as applied in the context of specific regulatory guidance documents (for example, in SR 11-7).

3 For example, in the course of the financial crisis, many banks posted daily trading losses many times greater than their Value at Risk (VaR) estimates. In practice, the VaR market risk models applied by many banks did not adequately capture tail-risk credit events, produced results that unduly reflected recent benign experience, and were built on assumptions (implicit and explicit) on market liquidity and diversification across asset classes that were not reflective of subsequent actual experience in stressed financial markets.

4 For example, <https://www.fca.org.uk/news/statements/statement-communications-relation-priips>

5 <https://www.fca.org.uk/publication/thematic-reviews/tr15-02.pdf>

6 For example, the UK PRA's David Rule notes in his January 2017 speech, Solvency II one year in: *"my observation is that firms proposed considerably more changes that reduced rather than increased capital requirements."* <https://www.bankofengland.co.uk/speech/2017/solvency-2-one-year-in>

### Systemic risks of models

Models may also pose systemic risks, beyond the risks posed to individual firms. For example, “herding” around common approaches and calibrations, or indeed the building blocks or inputs of many models (such as regulatory-prescribed or vendor models or data sets) could lead firms, consciously or unconsciously, to act in concert, amplifying market stresses or reinforcing market cycles.

In practice, methodologies or approaches can become commonly applied across different firms, through good practice and/or acceptance by regulators, or through prescription of standardized approaches. While this can support a consistent quality of modeling and dissemination of good practices, it may also systematize shortcomings in approach that may lead multiple firms to make unintentionally similar poor decisions or to suffer losses.

These trends may, potentially, and inadvertently, be magnified by supervisory activities, including peer comparison, benchmarking, or quantitative standards. For example, a number of current supervisory initiatives have objectives to increase convergence in modeling, model outputs, and supervision. To the extent that systemic risk increases as decision-making is aligned in different firms and sectors, an increase in systemic risk could be an unintended consequence of these initiatives.

### How are supervisors responding to concerns about model risk?

In the following sections of this report we discuss what we consider to be the most notable recent trends in the supervision of models that are giving rise to specific supervisory activities and initiatives:

#### Organization, governance, and senior management understanding of models:

- Governance and oversight represent the major focus of day-to-day supervision of models, reflecting the critical role that model misunderstanding and misuse, and failure of model risk and broader governance, has played in real-world examples of major model-related loss. Supervisors expect regular board and senior management engagement in model risk management, with a sufficient understanding of the model and its limitations to exercise effective challenge. The internal organization (for example, dedicated model risk teams) should support the effective execution of the model risk management framework.

#### Downward drift in capital strength:

- Supervisors expect models to change over time, for example to reflect improving modeling practices and changes in the risk profile of the firm. However, we see supervisors being mindful of the risk that updates to model parameters and calibrations could lead to a downward drift in capital strength over time. This may include where models are gradually “reverse-engineered” towards pre-conceived results. Supervisors monitor models over time, and are seeking to ensure that major changes are being identified and submitted for supervisory review.

### Divergence of models between firms:

- Banking and insurance supervisors have observed that results vary between different firms’ models for a given set of risks. This raises concerns over the comparability of results and solvency based on models, and has given rise to supervisory initiatives in both sectors:
  - The ECB launched its Targeted Review of Internal Models (TRIM) in 2015, as “*a project to assess whether the models currently used by banks comply with regulatory requirements, and whether their results are reliable and comparable.*”<sup>7</sup>
  - The TRIM covers all areas that are likely to have an impact on model outputs, in particular credit, market and counterparty credit models, and has had a particular practical focus on data. Its principles are aligned with SR 11-7, and focus on model lifecycle aspects such as model governance, validation and documentation. The ECB expects to conclude the TRIM in 2019.
  - The European Insurance and Occupational Pensions Authority (EIOPA) is conducting ongoing comparative studies<sup>8</sup> to review the consistency of models used by insurers, leading, for example, to a subsequent opinion intended to reinforce supervisory convergence on modeling of the dynamic volatility adjustment, and the publication of the first in a series of regular annual reports on market and credit risk modeling.<sup>9</sup> EIOPA intends to provide support and advice on models to national supervisors, to participate in supervisory colleges, and to develop model indicators to help supervisors to detect gradual weakening of model calibrations over time.<sup>10</sup>

7 <https://www.bankingsupervision.europa.eu/about/ssmexplained/html/trim.en.html>

8 [https://eiopa.europa.eu/Publications/Other%20Documents/Update\\_on\\_internal\\_model\\_consistency\\_projects.pdf](https://eiopa.europa.eu/Publications/Other%20Documents/Update_on_internal_model_consistency_projects.pdf)

9 [https://eiopa.europa.eu/Publications/Reports/EIOPA\\_comparative\\_study\\_on\\_market\\_and\\_credit\\_risk\\_modelling.pdf](https://eiopa.europa.eu/Publications/Reports/EIOPA_comparative_study_on_market_and_credit_risk_modelling.pdf) and [https://eiopa.europa.eu/Publications/Opinions/2017-12-20%20EIOPA-BoS-17-366\\_Internal\\_model\\_DVA\\_Opinion.pdf](https://eiopa.europa.eu/Publications/Opinions/2017-12-20%20EIOPA-BoS-17-366_Internal_model_DVA_Opinion.pdf)

10 <https://eiopa.europa.eu/Publications/Administrative/EIOPA%20SPD%202017-2019%20including%20AWP%202018.pdf>



- The UK Prudential Regulation Authority (PRA) has for some time used a “quantitative indicator” framework to help supervisors identify areas for greater review scrutiny during model approval reviews. The PRA uses quantitative indicators in its assessment of the model’s calibration, although it does not treat compliance with particular indicators as determinative of approval.<sup>11</sup>

#### Identification and risk assessment of portfolios of models:

- Firms may be exposed to risks from their use of many different types of models, not just those subject to specific rules under the prevailing regulatory framework. Supervisors are focusing attention on different types of models, for example the application of credit assessment models in valuing illiquid assets on insurers’ balance sheets.<sup>12</sup> The European Banking Authority’s (EBA) Guidelines for Common Procedures and Methodologies for the Supervisory Review and Evaluation Process (SREP) Guidelines stress that model risk should be assessed for all models, not just those calculating regulatory minimum own funds, and the ECB’s draft Guide to Internal Models notes that “*Institutions are expected to implement an effective model risk management framework for all models in use*”. In our view, firms need to define metrics to assess model materiality for all models along various dimensions, and importantly must understand how they interlink.

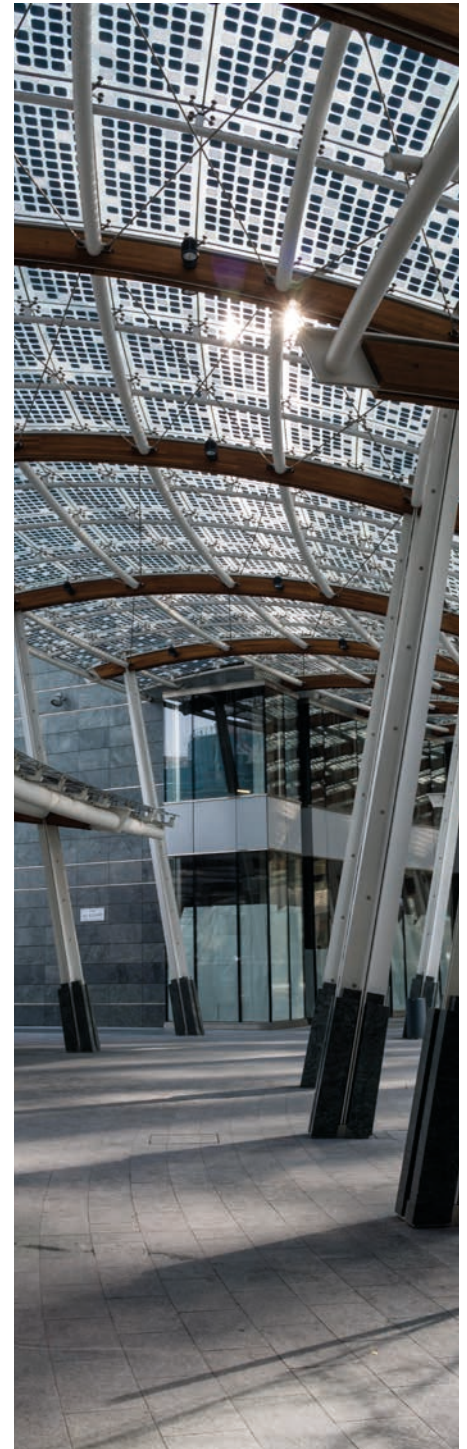
#### Definitions of “Model” and “Model Risk”

Industry and regulators have long struggled to define what constitutes a “model”. In general terms, “model” may capture a broad range of calculation and estimation techniques. However, for practical application a broader definition than is warranted risks creating an unmanageable process.

This debate often converges on the definitions of a “model” and “model risk” provided in SR 11-7, and these definitions are likely to be familiar to anyone working in a financial risk management function:

- **“Model”** refers to a quantitative method, system, or approach that applies statistical, economic, financial, or mathematical theories, techniques, and assumptions to process input data into quantitative estimates.
- **“Model risk”** means the potential for adverse consequences from decisions based on incorrect or misused model outputs and reports.

While SR 11-7 provides working definitions that can be applied in practice, we consider it important to recognise the potential loss of generality. For example, model risk may arise outside of sophisticated valuation or tail loss estimates, and supervisors expect organizations to apply model risk management principles to all models, not just those fulfilling a specific regulatory function.



11 <https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/supervisory-statement/2016/ss1716.pdf>

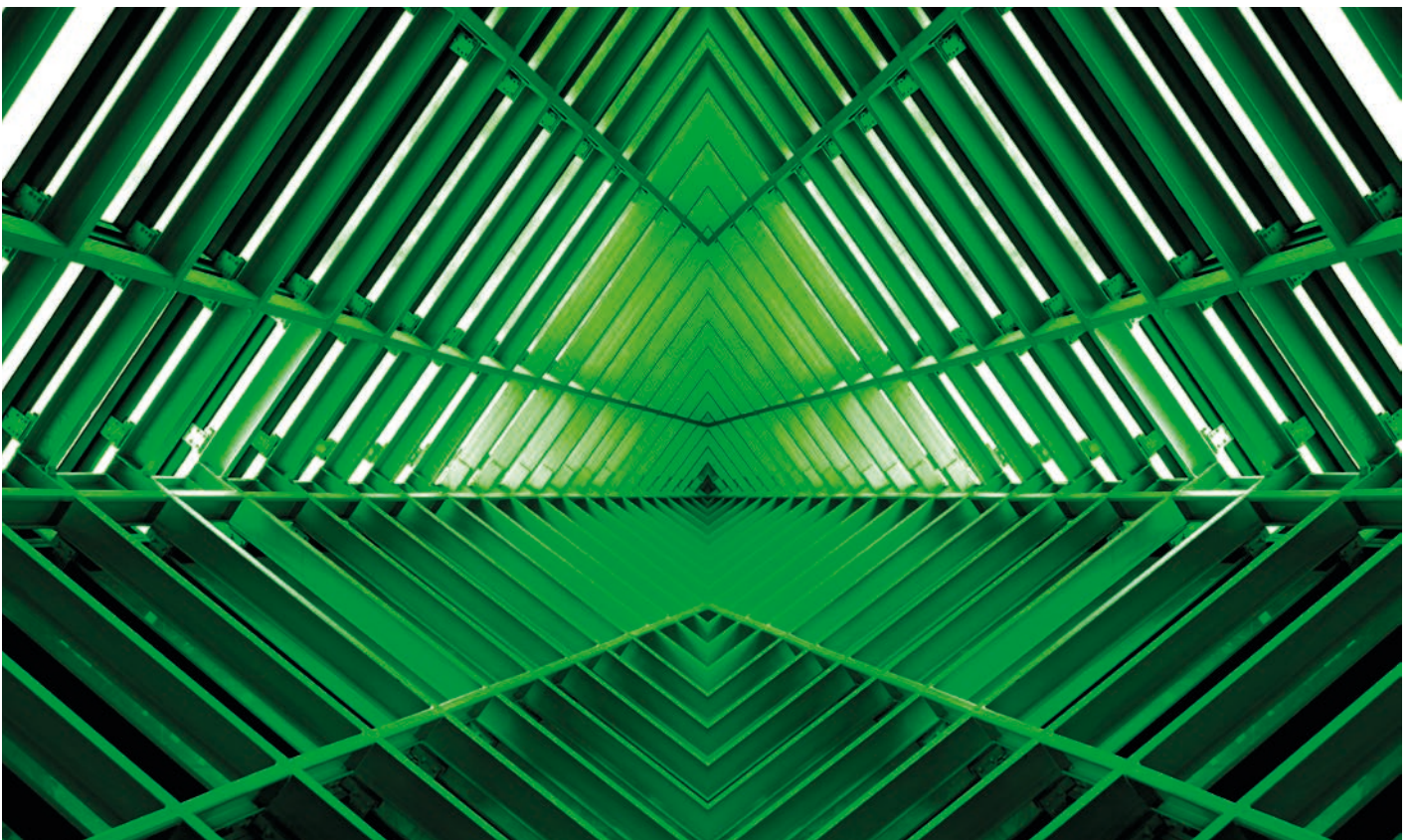
12 <https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/supervisory-statement/2017/ss317.pdf>



### Errors in model use and management – examples from outside of financial services

Models have been used in different forms through history, and, for just as long, have created risks of loss. Crystallized examples of model risk from outside of the financial services industry include the following notable examples:

- **Application of a model outside its area of validity:** Early shipbuilders found an approximately linear relationship between a boat's displacement and the amount of ballast required, determined using empirical experience. For small changes in the "state of the world" variable (i.e., the ship's displacement), this relationship held, but when extrapolated for larger vessels, the relationship breaks down. This led to a number of notable maritime disasters (for example, the sinking of the "Vasa" in Stockholm in 1628).
- **Sample bias in model data:** Prior to the 1936 United States presidential election, *The Literary Digest* carried out a poll of voting preferences. With over 2 million questionnaires returned, *The Literary Digest* called the election for Alf Landon. Franklin D. Roosevelt won the election with a large majority. The extrapolation had failed to consider a relevant variable in its "state of the world" model – a prior probability that readers of *The Literary Digest* and other groups polled would vote for Landon.
- **Flawed model design:** Opened in 2000, the London pedestrian Millennium Bridge developed a sideways wobble as soon as a certain number of people tried to walk on it. With many years of experience of bridge building, the impact of vertical random forces was well understood. However, the modelled "state of the world" and inter-relationships did not recognise a feedback loop, whereby humans adjust their gait in response to lateral vibrations, and this inter-relationship was missing from vibration models.



# Organization, governance, and senior management understanding of models

*“Developing and maintaining strong governance, policies and controls over the model risk management framework is fundamentally important to its effectiveness. Even if model development, implementation, use, and validation are satisfactory, a weak governance function will reduce the effectiveness of overall model risk management.”*

**Supervisory Guidance on Model Risk Management, Board of Governors of the Federal Reserve System and Office of the Comptroller of the Currency (SR 11-7)**

That supervisors expect financial services firms to exercise effective governance over models, along with other material aspects of the firm’s operations, is not a new concept. Indeed, a great amount of the regulation on model risk management is concerned with activities that regulators expect firms to carry out as part of model risk governance, for example model validation, policy-setting and documentation.

However, the use and oversight of models are also the major practical focus of supervision, and an area of expanding supervisory expectations. Supervisors commonly look to boards as the final safeguard in the model risk management framework, and accordingly place significant emphasis on the effectiveness of their oversight. For example, in Canada the Office of the Superintendent of Financial Institutions’ (OSFI) Enterprise-Wide Model Risk Management for Deposit-Taking Institutions (E-23) guideline notes that *“Regardless of the governance structure used by an institution, OSFI expects that an overriding principle of effective oversight over the use of models’ be maintained.”*

Supervisors also expect internal organization that supports the model risk management function (for example, clear allocation of responsibilities and the establishment of model risk teams with appropriate stature within the organization), and robust governance policies and processes to cover all areas of model design, deployment and use. We would expect supervisors to consider, for example, the following questions:

- Does the board understand the shortcomings of the model, in the context of its intended and actual use, and therefore when and where more or less reliance should be placed on its results as an input to decision-making?
- Is the model sufficiently transparent for the board to understand and oversee the model effectively?
- In what circumstances might the model not work as intended?
- Does the model unduly represent the views or interests of a single department, function, group or individual?
- What is the quality of model data and assumptions, and how do these affect model outputs?
- Are model development incentives likely to lead to model risk increasing or reducing

over time?

We expect supervisors to look for evidence of robust discussion and challenge of models and their results at the senior oversight level, particularly around key or finely-balanced judgements or contentious areas, supported by meaningful management information. Importantly, all members of the board are not expected to have a comparable level of technical understanding of how the model operates;<sup>13</sup> but supervisors expect all members of the board to understand key strengths, limitations, assumptions and judgements of the model, and to understand the steps that the board has taken to satisfy itself on the appropriateness of the model.<sup>14</sup> Supervisors want to see all board members understand what “shifts the dial”, and by how much.

13 As Andrew Bailey, then CEO of the UK PRA, stated in a 2015 speech on Governance and the role of boards, “[t]o be clear, we do not expect Copula fluency for all.” <https://www.bankofengland.co.uk/speech/2015/governance-and-the-role-of-boards>

14 For example, <https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/supervisory-statement/2016/ss1716.pdf>

### Model risk reporting

Model risk reporting provides the primary basis for consideration of model risk at board and senior management levels. We therefore expect it to be core information for the supervisor to assess in forming a view of whether effective discussion is being enabled and is taking place at board level.

Model risk reporting should link clearly to the organization's adopted risk appetite for model risk. Reporting should provide insight into model risk; for example, it is expected to go beyond factual reporting of validation findings. Supervisors will look for evidence (for example, in board or committee meeting minutes) that reporting is supporting substantive discussion of model risk, and is driving model risk management actions.

Equally, we expect supervisors to look for evidence that boards are aware of the limitations of model risk reporting (for example, resulting from the complexity of underlying calculation processes), and are prepared to challenge its conclusions.

Designing and delivering effective model risk reporting, and the relevant qualitative and quantitative measures that sit behind it can pose significant challenges in practice, for example:

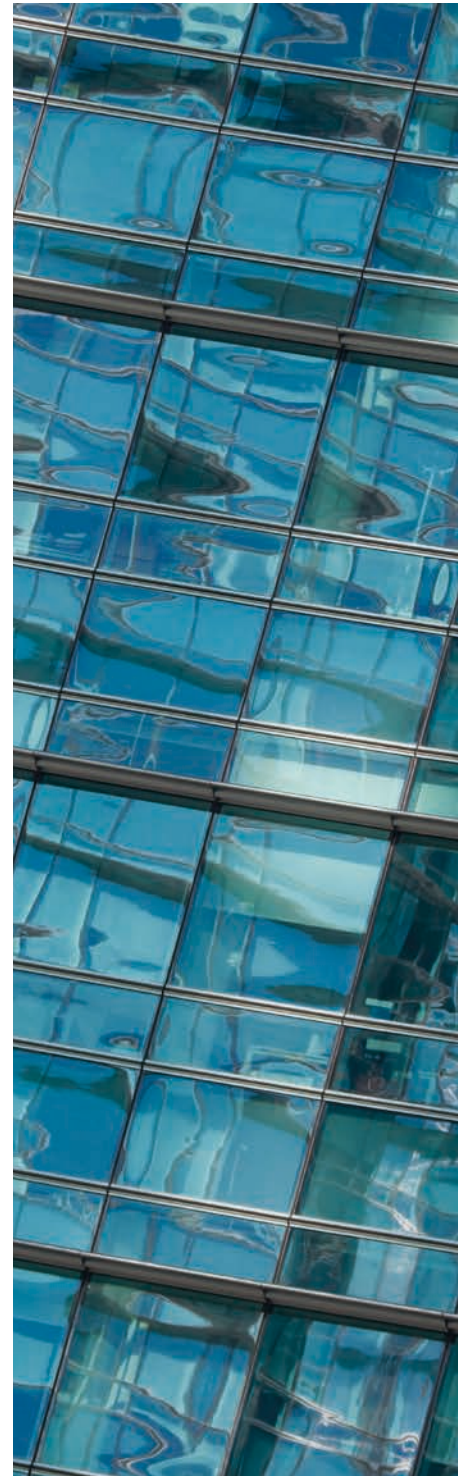
- determining how to measure the impact of models in a way that allows comparison and ranking of the risks posed by potentially very different models;
- how to define metrics, for example linked to model risk appetite;
- determining an appropriate frequency of reporting;
- implementing required infrastructure to deliver reporting, for example, databases and workflow tools; and
- how to aggregate reporting on individual models to provide a comprehensive and consistent view of model risk at a defined level of aggregation.

Model risk scorecards can be applied effectively to report on model risk throughout the model lifecycle, supported by definitions of qualitative and quantitative risk measures and aggregation methodologies.

### Model use

Reporting prepared for the board and senior management can also serve as an indicator and record of the use of models, focusing on the practical application of the outputs of models.

How organizations use models is one of the most important practical "litmus tests" applied by supervisors in their assessments of firms' modeling and governance. Supervisors focus on how models are used because misuse of models (including where models are applied for purposes for which they are unintended or for which they have not been validated) is one of the major drivers of model risk. However, appropriate use of models also tends to lead to model improvement, as model users identify shortcomings, and firms develop models to improve their performance. The ways in which models are used (which may be various for any particular model) may therefore both increase and decrease supervisory concern about model risk.





# Model lifecycle management

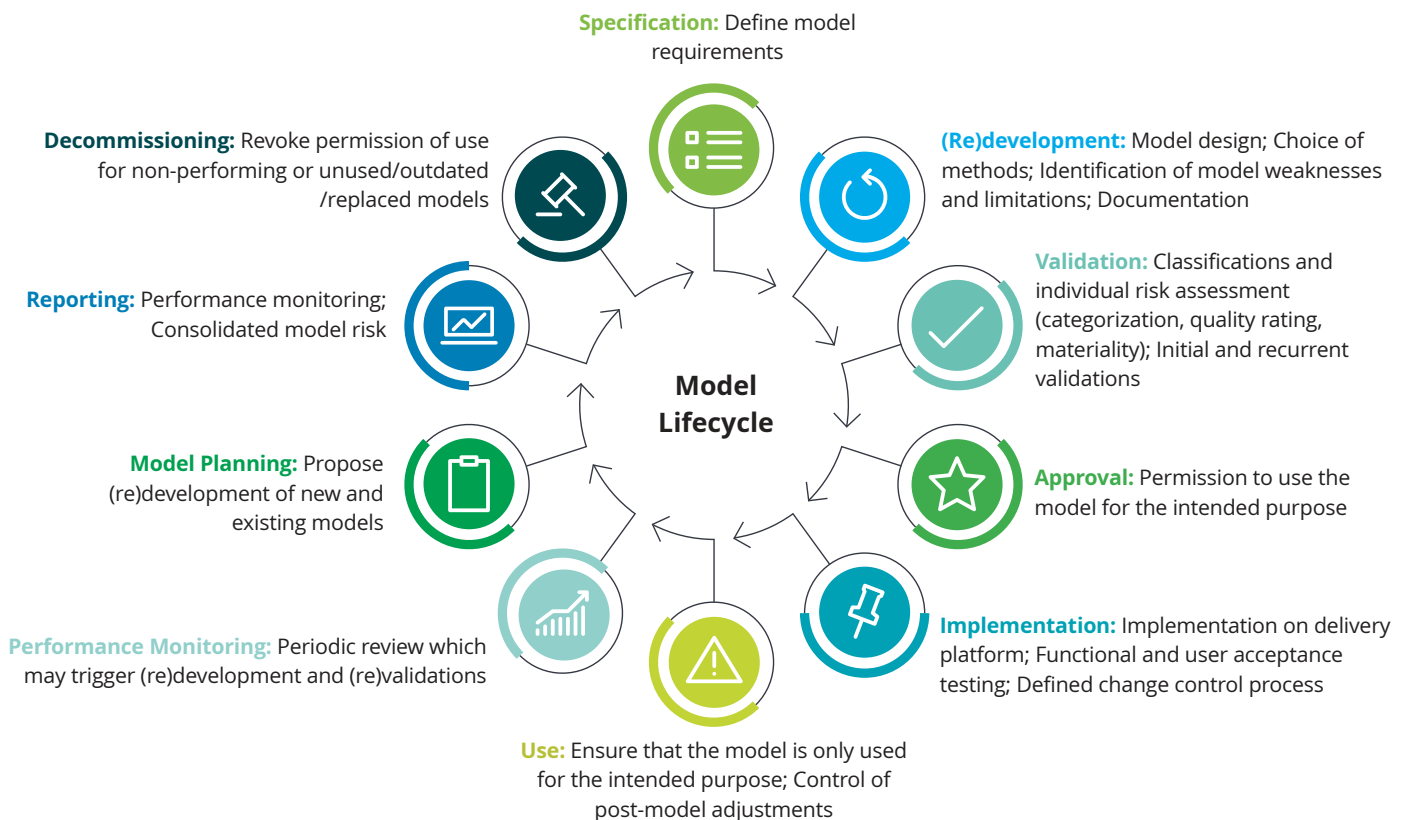
*“The model life cycle includes the following steps: requirements analysis, development, implementation, testing, use, validation, maintenance and changes.”*

ECB Guide to Internal Models (draft), European Central Bank

As we noted earlier in this report, model risk may arise from the development, implementation or use of models, or from a combination of these factors. By defining and managing the model lifecycle, firms can demonstrate to supervisors that model risk is being managed across all of these dimensions of potential risk.

The model lifecycle is broad, and covers all stages of model development, implementation and use. We define the model lifecycle using the framework shown in Figure B.

Figure B

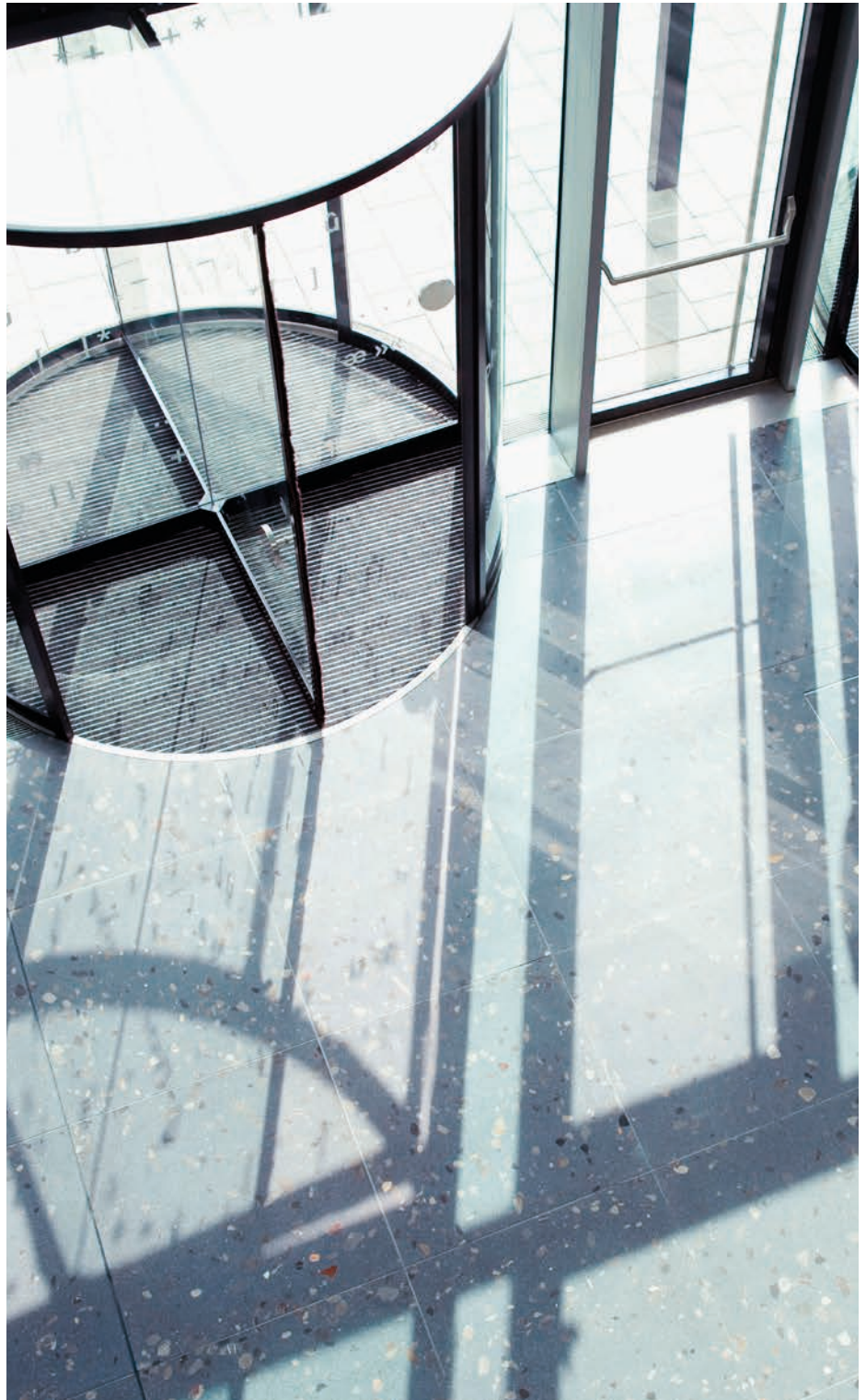




Firms can use workflow management systems to help explain and build supervisory confidence in the strength of model risk management and the mitigation of model risk. As well as increasing operational and process efficiency in relation to models (for example, by facilitating the use of automation tools), management of the model lifecycle can strengthen governance at each point in the workflow, supporting the implementation of controls and clearly defining scopes of responsibility.

For example, workflow management systems can be applied to provide:

- role-based responsibilities at each control point in the workflow process;
- management of the model control framework, proportionally to the risk posed by each model;
- consistent standards to apply to each model (for example, on the model inventory, taxonomies, data standards and documentation);
- planning of resources and workflow-oriented deadlines for each task;
- facilitated interaction between staff responsible for different parts of the lifecycle (for example, transfer of information between the first and second lines of defense);
- issue management and resolution;
- status reporting to the model inventory;
- reporting to model users and managers; and
- regular evaluation of the model lifecycle.



# The role of model validation

*“A firm should independently validate or otherwise conduct effective challenge of models used in internal capital planning, consistent with supervisory guidance on model risk management. The model review and validation process should include an evaluation of conceptual soundness of models and ongoing monitoring of the model performance. The firm’s validation staff should have the necessary technical competencies, sufficient stature within the organization, and appropriate independence from model developers and business areas to provide a critical and unbiased evaluation of the estimation approaches.”*

## Federal Reserve Supervisory Assessment of Capital Planning and Positions for LISCC Firms and Large and Complex Firms, Board of Governors of the Federal Reserve System (SR 15-18)

From the perspectives of regulation and supervision (as well as, usually, from the perspective of the board itself), validation of the model by a function that is technically rigorous, but independent from the model builders, is well-established as one of the most important aspects of the model lifecycle.

Comprehensive, well-structured and well-executed validation, conducted on an independent basis, can provide supervisors with significant comfort over financial services firms’ deployment and use of models (and is expected to include those models that are developed externally, e.g., vendor models).<sup>15</sup> For regulatory capital purposes, model approval cannot be granted in the absence of effective validation, and regulators apply detailed guidance on appropriate standards for validation in these contexts.<sup>16</sup>

Model validation can be applied effectively at defined points in the model lifecycle. In particular:

- **initial validation** should consider the appropriateness of the proposed model for a given business use, considering:
  - conceptual soundness;
  - quality of model design and construction;
  - model implementation (in particular, IT implementation);
  - the model control environment (e.g., access and/or version controls);
  - model assumptions, expert judgements, and their limitations;
  - internal and external model data inputs;
  - testing of model performance and limitations, for example through sensitivity, stress, benchmarking and outcomes-analysis (e.g., back-testing of model outputs); and
  - model documentation (including of data

inputs);

- **ongoing review and validation** should be performed at least annually (for example, through outcomes-analysis) to confirm that the model is still operating appropriately, and whether additional model development and/or validation activities are required. The appropriate frequency of review and re-validation depends on the nature of the model and the risks it covers. Model limitations and model operating conditions should be monitored to identify risks that the model may not perform as intended; and
- **major changes** to the model (including accumulations of minor changes) should prompt consideration of revalidation, up to the extent of full initial validation in the event of major model redevelopment. Models should operate in a locked-down environment and changes should follow embedded change-management controls and testing.

15 For example, Australia’s APRA indicates in APG-223 that it is good practice for authorized deposit institutions evaluating residential mortgage loans using vendor models to validate those models using internal tests, rather than relying on the model vendor to provide validation services. OSFI’s E-23 guideline states that “Aside from outsourcing the model development phase, adopting a vendor product does not eliminate the need to apply a similar process for vetting, approval, ongoing validation, decommissioning and overall documentation, as would be conducted for in-house developed models and data sources.”

16 For example, Solvency II sets out validation standards for insurers’ approved internal capital models. The ICAEW’s Assurance Framework on Banking Regulatory Ratios, developed following a request of the UK PRA, provides a framework for assurance over regulatory ratios calculated by banks, including where models are applied.

Implementing an approach to ongoing validation based on cycles and change control, following an initial deep-dive validation, can improve the cost-effectiveness of validation, while meeting supervisors' expectations by focusing on key points in the model lifecycle where model risk is highest.

Supervisors will expect model validation to be performed by appropriately skilled resources who, vitally, are independent of model development, implementation and use. Validators also need to have sufficient technical knowledge to be able to validate key model assumptions and judgements; it is not sufficient for them merely to confirm that a process has been followed.

#### **Case study - machine learning for model validation**

Our experience working with clients in financial services is that firms can substantially improve the effectiveness and efficiency of model validation through applying machine learning and advanced analytical techniques.

For example, benchmarking analysis evaluates modeling uncertainty by comparing the outputs of models to alternative modeling choices. We have applied machine learning techniques (for example, neural networks, random forest, stacked average or gradient boosting models) to develop reference challenger models for model benchmarking that outperform the model under validation and reduce misclassification rates.

This allows second and third line of defense functions to produce KPIs that compare challenger models to existing models, and which act as inputs for model risk quantification.





# Downward drift and divergence of model results

*“It is likely that many aspects of internal models will change over time as knowledge about risk modelling improves, and supervisory authorities should accordingly have regard to current information and practice in making their assessment of the internal model to ensure that it keeps pace with recent developments.”*

## Commission Delegated Regulation (EU) 2015/35 (Solvency II Delegated Acts)

Once regulation has moved away from prescribed approaches, supervisors have no guarantees on the results that firms will reach using their own models (with the absolute value of capital numbers being of particular concern). Model results should, in theory, be more tailored to the individual risk profile of each organization, but how can supervisors be confident that the results are appropriate, or make comparisons between firms?

This question tends to be addressed in regulation through the following common mechanisms:

- **Standards for calibration and capital strength:** Importantly, models may be expected to produce outputs to a prescribed level of calibration, for example 99.5% VaR over one year for European insurance capital models.<sup>17</sup> Regulations envisage calibrations being assessed based on both model inputs (e.g., assumptions) and outputs (for example, insurance regulations provide for firms to run their models on common sets of data to allow benchmarking of outputs).
- **Model development standards:** Regulations define standards for the quality of models, with particular emphasis on the quality of input data, assumptions and methodology.

- **Review of model changes:** Supervisors must generally review and approve changes to approved models. We expect them to place particular focus on changes that materially shift outputs, including incremental shifts over time.

Model calibrations and comparability are made more challenging to supervise because firms need to develop their models over time. Evolving models could well diverge over time, and good practices for modeling also develop, meaning that a model's methodologies may become out of date, or, more importantly from a supervisor's perspective, may rely on methodologies that come to be seen as flawed (for example, models relying on the Gaussian copula approach following the financial crisis).

Supervisors are further concerned that, all other things being equal, model development incentives will tend most often to favor model developments that could run counter to the supervisor's objectives. While model developments may increase or lower a firm's assessment of a particular risk, we see supervisors concerned that changes that produce lower assessments may be prioritized, or may be subject to a lower standard of validation and review, leading to a preponderance of changes that weaken calibrations over time.

This may lead to a number of undesirable consequences from the supervisor's perspective, for example, lower capital strength, inadequate pricing, reserving or other key pillars of financial resilience, or poor consumer outcomes through inadequate assessment of risks to customers.

These potential consequences make calibration a significant area of focus for current supervisory activities (although supervisors do recognize that models should not be unduly conservative or over-calibrated). As we discuss further below, these supervisory activities include, in particular, the use of quantitative standards and indicators, benchmarking, and supervision of model changes.

**Quantitative standards and indicators**  
Supervisors use quantitative standards and indicators to provide measures independent of the firm's model with which to assess the model's output, both at the point of regulatory approval (for approved models) and for monitoring drift in outputs and calibrations thereafter.

<sup>17</sup> Directive 2009/138/EC (Solvency II) Article 101. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32009L0138>



Supervisors do not necessarily treat such measures as hard limits. For example, in the UK, the PRA states clearly that the quantitative indicators that it uses in its assessment of model calibrations for insurers are not determinative of model approval, but rather triggers for in-depth review.<sup>18</sup> However, quantitative standards may also provide hard limits or “guardrails” to model calibrations, for example in the case of the standardized output floor agreed by the Basel Committee on Banking Supervision (BCBS) in December 2017, and the introduction of a binding risk-insensitive leverage ratio of 3% (with additional buffers for Global Systemically Important Banks (G-SIBs)).<sup>19</sup>

### Model benchmarking

Evidence has shown that models produce different results for similar risks between firms. This has led to a number of supervisory initiatives across the financial services sector that involve the benchmarking of models between firms, including the following:

- The ECB’s ongoing TRIM exercise. The ECB’s objectives include the reduction of inconsistencies and unwarranted variability resulting from the modeling freedom provided by the current regulatory framework.<sup>20</sup>
- The EBA’s review on the consistency of Risk Weighted Assets (RWA) for banks, which is intended to identify and understand material differences in RWA outcomes, and to formulate policy solutions to enhance convergence between banks and to improve disclosure if needed.<sup>21</sup>

- EIOPA’s Internal Model Consistency Projects focused on market and credit risk (which it expects to review and report on annually for the next few years), modeling of sovereign exposures, and modeling of the dynamic volatility adjustment (on which EIOPA has issued an opinion with the objective of reinforcing supervisory convergence).<sup>22</sup> EIOPA intends to provide support and advice on models to national supervisors, including participating in supervisory colleges.<sup>23</sup> European Commission proposals could also see EIOPA assume a greater role in the approval of models, including issuing opinions on individual models, with the intent of avoiding divergence in model standards and outcomes.

### Supervision of model changes

We expect supervisors to treat effective supervision of model changes as essential to avoid the risk of deteriorating model standards over time. Supervisors do not have the capacity to review every model change, and hence firms are generally expected to submit only those meeting a threshold of significance (including accumulations of individually more minor changes) to the supervisor for approval.

Demonstrating robust internal processes to monitor, evaluate and validate model changes is core to building supervisors’ confidence that model changes are being appropriately managed.

### Developing trends in supervision

We expect supervisors increasingly to use benchmarking as an analysis tool. Firms should expect to receive information requests from supervisors, and we expect supervisors to use new sources of data (e.g., Single Supervisory Mechanism (SSM) Benchmarking and Solvency II reporting) to analyze model results across the industry.

In our view, firms are also increasingly likely to see quantitative constraints applied to their model results, and as a consequence potentially changes to the incentives to seek model approval. This could, in time, pose a challenge to model approval processes, which place considerable weight on firms’ own use of their models to demonstrate the firm’s reliance on the model being assessed.

We would also see supervisory trends towards model consistency (including consistency of definitions) and benchmarking as, at face value, carrying the risk of increasing systemic risks caused by models, where they drive firms towards common approaches, outputs or conclusions. Firms should, in our view, consider market-wide risks as part of robust stress and scenario testing, and should consider the management actions they may employ, for example where large parts of the market unintentionally take similar actions in extreme scenarios.

18 <https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/supervisory-statement/2016/ss1716.pdf>

19 <https://www.bis.org/bcbs/publ/d424.pdf>

20 <https://www.bankingsupervision.europa.eu/about/ssmexplained/html/trim.en.html>

21 <http://www.eba.europa.eu/risk-analysis-and-data/review-of-consistency-of-risk-weighted-assets>

22 [https://eiopa.europa.eu/Publications/Other%20Documents/Update\\_on\\_internal\\_model\\_consistency\\_projects.pdf](https://eiopa.europa.eu/Publications/Other%20Documents/Update_on_internal_model_consistency_projects.pdf) and [https://eiopa.europa.eu/Publications/Opinions/2017-12-20%EIOPA-BoS-17-366\\_Internal\\_model\\_DVA\\_Opinion.pdf](https://eiopa.europa.eu/Publications/Opinions/2017-12-20%EIOPA-BoS-17-366_Internal_model_DVA_Opinion.pdf)

23 <https://eiopa.europa.eu/Publications/Administrative/EIOPA%20SPD%202017-2019%20including%20AWP%202018.pdf>

# Identification and risk assessment of model portfolios

*“[C]ompetent authorities should determine the business/activity for which the institution makes material use of models. In conducting this assessment, competent authorities may look at the following areas, where institutions commonly make extensive use of models: a. trading in financial instruments; b. risk measurement and management; and c. capital allocation (including lending policies and product pricing).”*

## Guide for the Targeted Review of Internal Models (TRIM), European Central Bank

While many financial institutions use models for specific regulatory purposes (for example, to determine the risk weights to apply in the risk-weighted assets (RWA) calculation for banks), most models are developed to satisfy business or other reporting needs. Examples include pricing, strategic planning, asset-liability management, credit rating assessment, collateral management, anti-money laundering, trade surveillance, financial reporting (e.g., IFRS 9 impairment), and trading and portfolio allocation. We also see big data and advanced analytics opening new areas for sophisticated models, such as customer relationship management or anti-money laundering and fraud detection.

The risks to firms and supervisory objectives posed by models that are not directly applied in the regulatory framework are significant. For example, errors in insurers' pricing models could affect pricing and reserving adequacy, potentially creating solvency concerns. Banks may experience higher losses if credit models are not accurately calibrated.

While we expect supervisor-approved regulatory models, therefore, to remain a focus of supervision, supervisors nonetheless will expect firms to manage the risks posed by models across all areas of business and operations (for example, the EBA's SREP Guidelines<sup>24</sup> state clearly that supervisors should assess validation/review processes to address model risk for all models used for decision-making, not just those used in the calculation of minimum capital).

For some sectors, we anticipate that this balance may indeed shift over time as more sophisticated models become more widely used outside of regulatory solvency-focused areas.

### Model inventories

A model inventory records all of a firm's models, their purpose and their application. The inventory tracks the model and records responsibilities through all stages of the model lifecycle, including model owners, users and uses, the assessment of materiality, validation and validation findings, model performance, model dependencies, changes to models over time, and model documentation. In our experience, a rigorous, structured and meaningful inventory framework and process can provide assurance to a firm's supervisor that all models are being identified and managed appropriately through the lifecycle.

In order to achieve this, firms require a clear and practical definition of what constitutes a “model”. Supervisors will expect firms to take a broad approach to identifying models across all areas of the business (one approach, for example, is to assume that any quantitative technique is a “model” unless established otherwise), and to assess materiality based on context, for example by contribution to P&L, or by measures of capital or liquidity drain.

Supervisors will expect to see a single overall inventory aggregating models across the organization, with a standardized approach to ensure consistency.

24 <https://www.eba.europa.eu/documents/10180/935249/EBA-GL-2014-13+%28Guidelines+on+SREP+methodologies+and+processes%29.pdf>

# How Deloitte can help

Deloitte works with clients across all areas of model risk management. Our team includes over 700 professionals covering all aspects of model risk, including financial engineers, mathematicians, actuaries, former regulators, former traders, data scientists, programmers, academics, risk and governance experts and project managers.

Deloitte has introduced and implemented leading industry practices at organizations across financial services, and has developed and implemented technological solutions that have helped our clients achieve scale and sustainability in their model risk management. Our experience spans a broad range of models, including those at the forefront of the industry and the most complex model-use environments.

Deloitte's model risk management services, set out below, are designed to enable financial services clients to improve modeling performance and model risk governance, across all components of their model risk management frameworks, while complying with the strictest regulatory rules and effectively navigating regulatory approval processes.

## Deloitte's model risk management services



## Model risk management as a managed service

In addition to discrete areas of project work, Deloitte also provides end-to-end model risk services to leading financial services organizations as an outsourced managed service. Deloitte's model risk managed service takes on all or part of a client's model risk management function, for example model validation. It provides clients with access to high quality and cost-effective model risk management services through our local teams and large offshore model risk practice. Deloitte uses defined, standardized processes, and our services support regulatory compliance.

Deloitte's services are integrated into your risk function and can operate using your existing workflow and technology systems. Alternatively, Deloitte's purpose-built in-house technology platform can be applied for workflow and process, model inventories, analytics and reporting and documentation management. Data can be processed on a secure Deloitte network, through cloud solutions, or through dedicated access to your systems.

Deloitte's managed service is delivered through a blend of resources from senior to junior levels. Delivery teams can be on-site, nearshore, or offshore, offering skilled and experienced specialists in all locations. A layer of senior management remains within the client's oversight to allow control, quality assessment and oversight to reside in-house.

# Appendix: How model risk management and its regulation differ across sectors

The use of models and management of model risk is well-established in financial services regulation:

- The US Federal Reserve's and Office of the Comptroller of the Currency's Supervisory Guidance on Model Risk Management, SR 11-7, is one of the most important statements of supervisory expectations on model risk management. While SR 11-7 has been followed by many regulatory publications on model risk management, for example from the ECB, EBA and a number of national supervisors (e.g., OSFI), it remains a benchmark for model risk management regulation, and is de facto applied in many jurisdictions outside the US.
- For the banking and insurance sectors, "internal models" may be approved to set regulatory capital requirements in some jurisdictions, a process that is subject to strict and extensive regulations under, for example, CRD/CRR and Solvency II.
- More broadly, models used for purposes other than calculating capital are subject to broad regulatory expectations on model risk management and general good governance.
- Further, more specific requirements also apply, for example where firms subject to MIFID II use algorithmic trading models.

However, while similar in objectives, the approach of each sector's regulation to models can nonetheless be markedly different, for example:

- While banks may seek approval to model certain discreet parts of the capital calculation with a focus on assets and their inherent credit and market risks, European insurers model the whole balance sheet (assets and liabilities) including diversification and correlations between risks.
- For European insurers, once the model is approved the regulatory framework requires both firm and supervisor to accept the calculated capital requirement except on an exceptional basis, placing a very significant emphasis on the supervisor's review of the model methodology, calibrations, governance and processes.
- For banks, the regulations provide for the exercise of supervisory review and discretion on the capital requirements calculated using models, placing a more significant emphasis on modeling outcomes, which the supervisors have extensive scope to adjust through capital add-ons.
- In other important jurisdictions, insurance solvency is assessed solely by reference to standardized calculations (illustrated by the ongoing debate at the International Association of Insurance Supervisors (IAIS) on whether model approaches should be permitted within its Insurance Capital Standard (ICS), currently under development).

Implementation of model risk management principles and supervision of models also varies markedly between financial services sectors and regulatory jurisdictions. Notable examples include:

- Major banks in the US generally have well-established implementation of model risk management principles, resulting in part from the significant focus placed on banks' model risk management by SR 11-7 and the later SR 15-18 (Federal Reserve Supervisory Assessment of Capital Planning and Positions for LISC Firms and Large and Complex Firms).
- Many large European insurers also have advanced model risk management capabilities, driven in part by the required standards to obtain capital model approval under Solvency II.

In our experience a focus in specific sectors from regulators has, in general, tended to advance implementation of formal model risk management by financial services firms. However, in some cases regulatory processes have encouraged increased formality that both firms and supervisors have considered to be excessive relative to its value for practical model risk management. Model documentation developed for regulatory model approval processes is a particularly pertinent example of this.



# Notes

# Notes

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