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FINANCIAL RISK MANAGEMENT

APPLICATIONS *in* MARKET, CREDIT, ASSET *and* LIABILITY MANAGEMENT *and* FIRMWIDE RISK

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PART FOUR

Firmwide Risk

CHAPTER 1

Introduction

BANKS AND RISK MANAGEMENT

Risk management has gone through a long journey in the history of corporate development. Modigliani and Miller (1958) proposed that in an environment without contracting cost, information asymmetry, and taxes, risk management among other financial policies is irrelevant to firm value creation. Sometimes it even lowers the value of the firm because it is seldom free. In the last decades the topic on the role of risk management in a value creation–oriented corporate world—especially in banks—has driven the evolution of the risk management practice. With the development of the computational technology and the witness of several major financial distresses, a sound infrastructure of the risk management systems becomes not only a regulatory concern but also corporate competitive advantage reality. However, the debate of the value and role of risk management in a financial institution still goes on. Some institutions retain the thought that risk management is just an answer to regulatory compliance or a defense system. The modern financial theory based on the capital asset pricing model and other related models is fundamental to the no-arbitrage principle. That is, excess returns can only be achieved by taking risks. This principle makes it necessary to recognize that risk management is not just a preference but is accompanied by the profit-chasing mandate of corporations.

The discussion on bank-specific risk management topics has to be picked up from the existence of banks as intermediary between borrowers and investors. The development of banks and the reliance on banks in the economic activities show that banks are a special corporate that provide unique services for parties from both sides. Banks in general provide special value to the corporate world by playing the role of three major intermediations: information, risk, and liquidity. As the intermediary between borrowers and investors, banks have more information about the type of resource available and wanted as well as the preferences of the two sides. This information asymmetry gives banks dominant roles in the resource allocation of the economy. Banks get their rewards by creating efficiency in the allocation process. In addition, banks are viewed as delegated monitors or evaluators of their borrowers. Because of the scale of economy and specialty, banks can provide monitoring services at a lower cost than the non-bank lenders. A bank must be responsible for the safety of the money from their lenders. Banks also offer insurance against shocks to a consumer's consumption by smoothing the resource allocation along a multihorizon path for the consumer. When the consumer has excess money, the money can be lent through banks to earn returns for the future. In case the consumer runs into a money crunch, emergency funds can be borrowed from the bank, which will have to be paid back from future income. Hence, banks' payment systems effectively connect the spatially and temporally separated trades.

The primary obligation of corporate entities, including banks, is to create value for their shareholders. However, through the intermediation service a bank provides to its customers, risk management in banks also brings social benefits as well. This is because banks not only create value for their shareholders but also have strong impact on the value of their customers. It is obvious that a bank's insolvency can bring the loss of its creditors. Risk management is in the core of the banking value creation and also a public benefit. Risk management is not just a certain methodology in a bank. It is about a culture and an end-to-end process that spirally moves a bank up into a value chain that demonstrates its core competitive advantage against its peers. A sound risk management process spans from identification, to measurement, to monitoring, to control, to optimal decision making, and back to identification.

As an information, risk, and liquidity intermediary, banks possess unique information on the general macroeconomic condition and customer and market status. Hence, banks have a unique position in risk identification. A well-known fact in any social science study is that past experience is not a guaranteed prediction to the future—although history does tend to repeat itself in disguised fashion. One of the prominent difficulties is the discovery of so-called "black swan" risks. In his famous book on the topic, Taleb (2007) borrows the term "black swan" for the situation where seemingly impossible or nonexistent events actually occur. Sometime overreliance on past experience will lead to loss of sight of a forthcoming crisis. One of the lessons learned from the 2007 financial crisis is to engage a forward-looking risk discovery practice that can identify risks that may not have existed in the past.

Traditionally financial risk measurement has been categorized into market, credit, liquidity, and other risks. Market risk represents the risks that are primarily driven by market variables including interest rates, foreign exchange rates, equities, and commodity prices. Credit risk is the risk underlying the default risk of counterparties ranging from retail customers to trading counterparties. Market risk and credit risk have traditionally been separately managed in most banking institutions. In traditional asset and liability management, market risk and credit risk have been separated in the way that the asset and liability committee manages interest rate risk impacts on profitability, and liquidity risks while the business units are concerned with the credit risk. It is an increasing trend to look at comprehensive risks in a more holistic way. All the potential risks in a particular business line or book are analyzed together without an artificial separation into driving risk types. For some risks this is also a prerequisite, for example, liquidity risk, which is usually a consequential risk from other risks.

Risk assessment includes both qualitative and quantitative measurement of the risk exposures of a bank. Such assessments require a joint effort of expert knowledge and scientific discovery techniques. Diebold et al. (2010) provide a knowledge theory that classifies risks into known, unknown, and unknowable. From a measurement point of view, a known risk is both identified and completely modeled. Note that a known risk is not deterministic but can be well measured. Diebold et al. (2010) specifically refer the models to fully specified probability distributions of potential profit and losses. An unknown risk is known to exist but cannot be modeled properly. A consumer behavioral risk such as prepayment risk serves as a simple illustration of the difference between these two risk types. The prepayment risk is certainly a well-identified risk. For consumer portfolios the well-specified statistical prepayment models can only be claimed to be known to a pool of a large number of such exposures. But it is much harder to predict the prepayment for a particular consumer. Unknowable events are events we experience as a surprise, arising from unseen events that are not identified.

One important factor to successful risk identification and measurement is data. Data quality is critical to identification and measurement of risks. Statistical analysis methodologies are often used in practice to overcome the issues in the observed data. For example, actual loss data are often censored and truncated to cause only partially available data for the study of a loss. In risk measurement the main target is often to estimate the probability of extreme losses. This is of course a much more difficult problem than estimating average losses and puts strong reliance on the model at hand being approximately a correct descriptor of potential extreme losses that can happen. Clearly, in risk measurement the analysis of model risk is central to the risk measurement process. In practice, data scarcity and disparateness also affect the measurement of the tail risk and are central components in practice in validating specific model assumptions.

The risks identified and assessed by a bank, as part of the financial disclosure, are subject to monitoring and reporting that must serve three different audiences: management, regulator, and the market. Shareholders, management, and debt holders are all motivated to manage risk, but they all have their own incentives, which are in some cases not aligned. For banks, given the role they play as financial intermediary in the society, they may also be viewed as having an obligation to the stability of the entire financial system. Due to the importance of banking stability to the entire economic system, bank regulators and the market also demand risk management disclosure of banks. Regulators want to make sure each individual bank operates fairly and responsibly. At the same time, regulators are also responsible to make sure the entire banking system remains stable under contagion effects.

To manage the level of risk in a portfolio, banks use risk mitigation tools. For example, for market risk, various hedging strategies are available to reduce the risk level in the portfolio. For credit risk, financial and physical collaterals and guarantees are popular risk mitigations. For liquidity risk, the ultimate risk mitigation tool is cash to neutralize the funding gap. With the recent development of the financial system and capital markets banks also have more innovative ways of risk mitigation. This includes credit derivatives to transfer the risk. Governments and central banks can also offer banks risk mitigation vehicles through guarantees and liquidity facilities.

A bank cannot merely control risk passively. It must offer its expertise in the risk intermediation area to remain valuable. One of the goals of risk management is to find an efficient way to mitigate risk so that the bank can have a tolerable risk level. For each identified risk, risk measurement helps measure the risk level and finds the right mitigation approach to protect the bank from taking unsustainable risk. For example, traditionally banks borrow short and lend long term to earn the term premium of interest rates. In this practice banks face both liquidity risk (as the bank must guarantee to be able to roll over its short-term funding) and interest rate risk (as the bank has to make sure, over the life of the lending instrument, the average short-term funding rate can be effectively lower than the long-term lending rate). In an economy full of uncertainty, it is almost impossible to fully secure any of these two guarantees. Banks must use dedicated hedging instruments like interest rate derivatives and liquidity facilities. Of course, hedging risk usually comes at a cost, reducing the inherent expected term premium to the bank.

As many of a bank's investment decisions are made under uncertainty, the ultimate decision weighs in the expected profits as well as the risks associated with the investment. Traditional value creation in a bank focuses on risk-adjusted returns and the bank's thresholds for investments contributing favorably. However, a bank's risk appetite, referred to as the level of risk the institution is willing to take in its value creation process, may also exclude the bank from participating in certain types of investments regardless of current market premiums. To implement the risk appetite in the business operations, a bank must monitor the materialized risk level in the bank against the risk limits and set strategic objectives optimally following the risk policies, all established by the risk appetite. Risk-based performance analysis of a business unit should preferably reflect the risk contribution of the unit to the entire organization.

Besides the economic motivations and regulatory requirements, the fast evolution of the computation technology contributes greatly to the shaping of the modern risk management practice. Modern technology allows banks to reduce risk calculation times and respond faster in business operations to new risk levels. It also allows more granular risk analysis and risk decompositions to account, trade, and position level, enabling more accurate views on exactly where in the bank's books shareholder value is created. The modern technology also allows banks to adopt more sophisticated approaches to scenario analysis and risk-based portfolio optimization.

Although this book focuses on the quantitative aspects of risk management we must emphasize that quantitative methodology and risk analytics are by no means the whole spectrum. At the very core of risk management is risk governance. It governs the entire risk management process. At the same time, it connects risk management to the entire business operations of a bank. Transparency is also an important factor. The key stakeholders must understand the assumptions and business rationale of the risk methodologies—although they do not have to know mathematical model details. Risk model development, validation, and deployment teams have responsibility to make sure models are soundly developed, implemented, and validated. However, they also have the important responsibility of communication.

EVOLUTION OF BANK CAPITAL REGULATION

Regulation is of course a strong driver for banks' evolution in risk management practices and the implementation of sound risk management systems. The costs of meeting regulatory compliance for banks have been significantly increasing over the years. The costs are both direct and operational related to implementation of sophisticated risk and compliance systems, disclosure processes, and retaining skilled people. In addition, there are significant indirect opportunity costs faced by banks as the new regulations have increased the minimum regulatory capital buffers. Over the three generations of the Basel accord, banks have seen ever-increasing capital requirements for the different risk types.

The first Basel accord in 1988 (Basel Committee, 1988) did not have a substantial impact on operational costs and risk systems; it simply required banks to slot credit exposures into gross tiers of risk-weighted assets. The next generation of the regulation focused on amending the regulatory standardized and internal models approach to market risk in 1996 (Basel Committee, 1996). At this time, many banks implemented internal value at risk (VaR) models on which capital requirements were based. The more sophisticated use of simulation models to calculate and price market risk for many banks drove investment into specialized risk technology and risk systems as well as skilled people. For the first time many banks recruited large teams of risk quants to manage the market risk models. In day-to-day business operations traders found their risk limits on books transitioning from simple delta and gamma limits to more sophisticated VaR limits.

The Basel I accord had a very gross assignment of risk-weighted assets for credits and had been criticized by many banks for not being risk sensitive since its inception. The next major update to the regulation therefore came with Basel II in 2005 (Basel Committee, 2005a), which required banks to report more sophisticated risk-weighted assets for credit risk than in the first accord. Basel II also brought necessary sophistication into the regulatory capital paradigm by introducing three pillars that set the minimal capital requirement (pillar 1), a supervisory review that encourages banks to improve their internal risk management practice in credit risk (pillar 2), and proper disclosure and market disclosure (pillar 3). Many banks were required to adopt the advanced internal ratings-based approach for retail and small and medium-sized-firm credits. For large corporates the foundation internal ratings–based approach was used and was largely based on external ratings. With Basel II the Basel accord for credit risk was model based for the first time and required banks to estimate model input parameters such as the probability of default, loss given default, and exposure at default for all its credit exposures. Basel II hence drove a significant investment of banks into credit scoring models, processes, and systems. The statistical modeling approach to analyze credit quality created a demand for skilled statisticians in banks. Large credit scoring model development and validation teams were built. At the same time the relative importance of the traditional qualitative credit analyst departments in banks decreased and credit lending was largely industrialized. The Basel II accord also instituted a standard practice for banks in risk-adjusted pricing of their credits. Hence, regulation drove significant investment not only in risk systems but also in implementing processes in the day-to-day use of traditional banking systems like loan systems. Banks were also looking for ways to arbitrage on their required capital, which contributed to a rising interest in packaging and issuing securitization instruments on some of the credit portfolios.

At the time of implementation of Basel II an important discussion arose between banks and regulators about the potential countercyclicality of the new credit capital buffers. This referred to the situation that, at good times, when the probability of default and loss given default inputs to the risk-weighted assets model was low capital requirements were also low. At bad times the opposite situation would occur and increase capital requirements. Potentially, this situation could lead to banks having to raise capital and increase offered customer rates at the exact time of a recession, contributing to countercyclicality. The regulatory response to stabilize capital requirements and avoid the countercyclicality was to demand the use of stressed and long-run probability of defaults and loss given defaults in calculation of capital requirements.

A remaining critique of the Basel II accord for credit risk is the fact that risk-weighted assets are summable and hence the regulatory capital does not take into account concentration and diversification. Many banks therefore have developed their own economic capital models for credit risk. At the time banks were implementing the Basel II accord for credit risk there was also a lively discussion about whether one should use the regulatory risk capital versus the economic capital model allocated risk when pricing credits.[1]

While Basel II certainly had the most significant impact on banks' credit risk analysis methods and lending processes the Basel II accord also instituted new capital requirements for operational risk, and in its second pillar focused also on banks' general process for capital assessment, with, for example, general guidelines on specific topics such as liquidity risk.

In 2005 the Basel II accord also added more advanced capital requirements for over-the-counter (OTC) derivatives counterparty exposure at default (Basel Committee, 2005b). The original 1988 amendment to Basel I used simplified current exposure and regulatory prescribed add-on factors. The new regulation allowed banks to use either an updated current

[1]While the economic capital model, regulatory required capital levels, and actual held capital were quite different in practice, some banks rescaled the economic capital model capital allocation so that they summed to the actual capital, achieving a full allocation of capital with concentration effects.

exposure approach, a standardized method, or an internal models approach to estimate the exposure. The calculated exposure was subsequently used in the Basel II prescribed model for risk capital. In the internal model method banks could use advanced multihorizon simulation-based approaches to price OTC derivatives at future times and subsequently aggregate exposure per netting set agreement. In addition banks could take into account collateral such as margining when estimating regulatory exposures. The regulatory exposure measure was subsequently adjusted by a regulatory assigned or internally calibrated alpha parameter to control for wrong-way risk and model risk. The regulatory assigned alpha was 1.4 and the internal model floor for alpha was set at 1.2. At this time many of the larger banks expanded their current market risk systems or invested in completely new systems to calculate the regulatory exposure measures for the OTC derivatives book. Hence, again significant investments were made in systems, processes, and skilled people. It also became standard practice to apply and monitor limits on counterparty exposures using a worst-case exposure measure—usually referred to as potential future exposure. Significant time was also spent on calibrating internal estimates of alpha to bring capital requirements down. These estimates focused on deriving an implied bank-specific alpha using the economic capital model as comparison to the regulatory exposure model.

The same Basel paper that introduced new capital requirements methods for OTC derivatives in 2005 also opened up a way for banks to more effectively account for credit hedges in Basel II. Previously, a hedged credit exposure could use the credit quality of the credit hedge issuer instead of the credit itself in the Basel II risk-weighted asset formula. This was of course only beneficial if the credit quality of the credit hedge issuer was better than on the credit itself. The substitution approach was criticized for being too conservative—essentially assuming perfect correlation between default events of the credit hedge issuer and the credit. The new double default formula allowed a more favorable approach than substitution by explicitly incorporating the correlation between the credit and the credit hedge issuer credit quality.

The next major change to the Basel regulation appeared in 2009, called Basel 2.5 (Basel Committee, 2009a, b) and was focused on updated capital requirements for market risk in trading book and a new capital charge for credit risk in the trading book, called the *incremental risk charge*. The new market risk charge added a stressed value at risk charge to the current charge for internal market risk models,[2] substantially increasing market risk capital requirements. The incremental risk charge was focused mainly on bonds in the trading book with liquidity trading horizons assigned to credits. No model was prescribed but since the regulatory requirement concerned the trading book and hence large counterparties, many banks used their existing portfolio credit risk models for large firms inspired by the Merton (1974) structural model. A particular popular implementation was the multifactor approach describing the firm's credit quality in terms of observed financial indices. Initially, some banks deemed the new incremental risk charge model as too complex, especially the required mapping of trading book credit exposures to liquidity trading horizons. This was because many banks' existing credit portfolio models at this time did not have a concept of trading and liquidity horizon, hence meeting the regulation required enhancements to existing systems.

While Basel 2.5 was being implemented in banks the regulators were also working on a more comprehensive response to the experiences in the 2007 financial crisis. The new

[2]The stressed VaR charge was implemented as the VaR obtained when market risk models were calibrated on a stressful period in the past.

Basel III accord—initiated in 2010–2011—introduced new, complementary capital and liquidity requirements (Basel Committee, 2011a, 2013a). On the firmwide capital side existing Basel II rules for capital were strengthened with, for example, new, more conservative levels of Tier 1 capital and requirements on countercyclical capital buffers.[3]

In Basel III a completely new capital requirement was introduced for OTC derivatives that was in addition to the 2005 method, founded in calculating default loss–based capital based on banks' exposures. The new credit valuation adjustment charge capitalized mark-to-market changes in counterparty exposures in addition to the 2005 default charge.[4] The rationale was that during the 2007 crisis a large part of the losses observed in the OTC derivative books of banks were due to mark-to-market and not realized. Still, banks had to devalue their OTC books in the crisis by substantial amounts due to sharply increasing market credit spreads of deal counterparties. The pricing and hedging of credit risk valuation adjustment was not a new practice. Many of the large investment banks had already adopted special credit valuation adjustment desks and invested in cutting-edge technology risk systems to actively price and manage credit valuation adjustments after the 2007 financial crisis. With the new regulation the investment in new credit valuation systems also spread to banks with smaller OTC books. However, the need for dynamic hedging of credit valuation adjustment was not as imminent as for the investment banks and many of the smaller banks still view credit valuation adjustments as a reserve component rather than a market-priced and hedged component.[5]

Alongside the new Basel III charge for credit valuation adjustments the most significant new Basel III charge was the requirement for banks to hold dedicated liquidity buffers. The new Basel III liquidity risk regulation underscores the importance of managing a liquidity contingency buffer. The focus is on maintaining a high-quality liquidity portfolio that can hedge liquidity outflows under stress scenarios, that is, to generate sufficient counterbalancing capacity. The key minimum reporting standards in the Basel III liquidity risk framework are a short-term, 30-day liquidity coverage ratio, and a longer-term structural ratio to address structural liquidity mismatches. There are also metrics for monitoring liquidity, for example, the monitoring of maturity mismatch, funding concentration, and unencumbered assets available (available for sale). Holding a liquidity buffer incurs opportunity cost just as holding capital does. Hence, one of the core activities by banks in their approach to Basel III liquidity risk is to institute a pricing of liquidity risk and hence pass the buffer costs to the consumers of the buffer. Contingent liquidity risk—which is what the liquidity buffer is held for—is mainly attributed to off–balance sheet commitments such as facilities that can be drawn by the bank's counterparties, but also for other items such as sudden funding withdrawals.

In 2012, 2013, and 2014, the Basel 2.5 2009 market risk updates were further enhanced (Basel Committee, 2012, 2013b, 2014a). New proposed market risk requirements included a move from value at risk to expected shortfall as a risk measure (also referred to as conditional value at risk, or CVaR, which is the term we will use in this book), introduction

[3]For example, there is both a 2.5% general capital conservation buffer as well as a 2.5% discretionary countercyclical capital buffer. The capital conservation buffer is designed to ensure that banks build up capital buffers outside periods of stress that can be drawn down as losses are incurred. Hence, outside periods of stress, banks should hold buffers of capital above the regulatory minimum.

[4]The credit valuation adjustment prices the fair mark-to-market adjustment of trades due to counterparty credit risk.

[5]However, the regulators have been clear in this matter. The Basel III credit valuation adjustment charge should be computed based on market credit spreads and not based on historical default information.

of longer liquidity horizons than the current 10 days for illiquid trades,[6] and a newly revised mandatory standardized approach—even for banks currently using the internal models approach. As CVaR is the expected tail loss beyond VaR market risk capital can increase with this new measure, although the regulators tend to agree to reduce the confidence level from 99% to 97.5% for the internal model–based approach.[7] However, the introduction of longer liquidity horizons than 10 days will surely increase market risk capital requirements for illiquid portfolios.

In addition to the evolution of the Basel regulation there have been several regional initiatives requiring banks to analyze capital sufficiency. These initiatives are especially focused on stress testing as the vehicle for analyzing the soundness of banks' current capital base. For example, in Europe EBA has required banks to report comprehensive stress tests, and in the United States, CCAR also requires banks to stress test their firmwide capital, in contrast to model-based charges, where the stress tests focus on putting capital limits under prescribed regulatory stress scenarios. The stress tests are by nature macroeconomic firmwide and focus on projected income and capital statements under stress. The relatively recent focus of regulators on stress testing as a key tool for analyzing risk and capital sufficiency is founded in the view that classical model-based charges represent mainly a historical view—either in terms of calibrating model parameters on history, or directly as in historical simulation approaches. It can also be viewed as a regulatory trend in distrust of models. Stress testing is viewed as a forward-looking risk analysis tool that should complement risk analysis based on historically calibrated models. Compared to model-based risk charges the stress tests and scenario analysis impacts can also be easier to communicate to the different stakeholders.

The focus on stress testing as a complementary supervisory tool followed quickly after the 2007 financial crisis. In the United States, the Supervisory Capital Assessment Program (SCAP) started in 2009 to focus on comprehensive stress test programs for US banks. It was followed by today's CCAR stress tests. Both SCAP and CCAR surely inspired the more recently introduced European EBA stress tests. The Basel regulation also promoted stress testing as a complement to model-based charges after the 2007 financial crisis. In 2009 the Basel committee paper on principles for sound stress testing practices and supervision promoted a comprehensive stress testing approach in banks (Basel Committee, 2009c), the concept of *reverse stress testing*. That is, identification of the still plausible but severe impact scenarios was made into stress testing practice in banks.

Guidelines on banks' capital planning process were introduced already in pillar 2 of the Basel II 2005 accord. However, the 2007 financial crisis and the stress test initiatives by (for example) EBA after the crisis have increased the importance of regulators promoting a sound capital planning process. Basel 2014 (Basel Committee, 2014b) focuses on guidelines for firmwide capital planning and in particular that banks take a forward-looking scenario-based approach to capital planning. As a response there is an increasing practice in banks to integrate the risk view into traditional financial statements such as profit-and-loss statements and capital views (balance sheet views). For profit-and-loss statements this requires banks to convert risk systems stress test outputs such as scenario expected losses into effects on banking book net interest margins, trading book profit and loss, and subsequently into scenario

[6] The original market risk VaR requirement considers a 10-day holding period for all positions. The introduction of liquidity horizons between 10 days and 1 year allows a segmentation on position close-out times connected to the position's market liquidity.

[7] For a normal distribution CVaR at confidence level 97.5% is equal to the VaR at 99% confidence level.

operating profit from stressed revenues and expenses. This integration of risk analysis into the finance view is important as it explicitly links the results of complex risk analysis to future potential income and balance sheet statements. Hence, it enhances the understanding and communication of risk analysis impacts on traditional financial measures, both within the bank and with external stakeholders.

As regulations have evolved and surely will continue to evolve banks need to further invest in systems, processes, and skilled people to minimally meet the regulation. However, regulatory capital requirements are only the minimal risk benchmarks. Banks must have a clear risk appetite definition that serves as internal management guidelines. Business policies and growth strategy must adhere to these guidelines. A natural question is whether a bank that invests more in risk management analytics and risk management processes can take advantage of this in business and hence give a return on the added investment. That is, can banks compete on risk analytics and the embedding of sound risk analytics in day-to-day processes such as product pricing?

CREATING VALUE FROM RISK MANAGEMENT

The use of sophisticated risk models and stress tests in understanding aggregate currency amounts at risk for the bank's portfolios is only one of the applications of risk analysis. Perhaps of even more importance is to understand the relative risks of positions and sub-portfolios. This is because relative risks are important in the process of risk-based value creation for banks. A clear understanding of risk costs down to granular levels improves the bank's understanding of which current products, customers, and counterparties are profitable. Moreover, with granular knowledge on risk costs the bank can be more competitive in product pricing. It can also avoid participation in markets where the risk compensation is not sufficient to cover the bank's risk costs. Clearly, banks that invest more in scientific data and economic rationale investigations on their customers and the market behavior are better prepared to capture such aspects in their risk models and hence subsequently take advantage of the knowledge.

The ultimate value creation from risk analytics is realized when it is deployed in day-to-day business strategy. As a result of regulation but also driven by market competitiveness banks are investing more in systems and processes to accurately price products and create strong incentives for value creation in their business lines. For example, branches' loans and deposits carry funds transfer rates with associated risk costs to signal the minimal customer rate needed for profitability. For traders, the fair values of the swap deals carry credit valuation adjustments and funding cost adjustments to signal to the trader the client spread needed to be profitable. It is also an increasing trend to centralize the hedging and risk management of more and more of the risk costs experienced in business. A centralization allows banks to better understand their exact concentration in certain markets, counterparties, and products, and, depending on a bank's risk appetite, measures can be taken to increase internal product charges or making changes to the product design. However, the centralization of risk measurement and management must also factor in that in some cases at least part of the risk responsibility has to be decentralized, both because of information asymmetry and to create the right incentives within the organization to actively manage the risk. For example, branches may possess unique information about local business that central credit models cannot capture. Removing the branches' responsibility for credit risk losses may therefore not be optimal.

Banks' risk models and risk analytics cannot be too simple. They must capture all the relevant risks down to the relevant level they are used and in particular the stylized facts that have been experienced in the past. Risk models must also include elements of forward-looking behavior—not relying solely on model validation—based on history. Since much of the business value from risk analytics derives from risk-based pricing there are strong demands that risk analytics can appropriately rank the relative risks of products. Banks with poor granular-level risk models and risk analytics run the risk of mispricing relative to the market and eventually end up with the nonprofitable portfolios. Banks with strong granular-level risk analytics and empirically and economically vetted risk models can be more competitive and can also avoid creating excessive risks in portfolios. They also create more trust in the organization for the use of risk analytics. It has become a practice sometimes to refer to model simplicity itself as an absolute good. The relevant concept is relative simplicity. For example, we would favor a more simplistic model instead of a more complex model if sufficient evidence is not available for the added complexity. As Albert Einstein once said, everything should be kept as simple as possible but not simpler than that.

Throughout this book readers can find numerous topics on risk-adjusted performance and risk-constrained optimization methodologies that help banks create value from proper risk management methods and models. Accurate risk measurement and monitoring of risk levels is clearly one core objective of risk management models. Using risk management models to also aid risk-based decision making, especially the performance analysis and profit maximization, also makes risk management models central to the business.

FINANCIAL RISK SYSTEMS

Besides all the economic and business drivers, the advance in the modern risk management is greatly indebted to innovations in technology. In fact the birth of the financial theories underlying the modern risk management practice, including Markowitz portfolio theory, Sharpe's capital asset pricing theory, Ross arbitrage pricing theory, and Black-Scholes option pricing, coincided with the commercialization of the computer technology. It is not an exaggeration to say that the growth of risk management goes hand-in-hand with the development of computational technology.

A financial risk management system is certainly the platform where the quantitative risk management methodologies materialize in practice. It usually refers to a computer system that can be used to

- manage risk models and risk data,
- construct risk scenarios,
- evaluate the bank portfolio under the risk scenarios,
- report on risk measures, and,
- in some cases also assist in risk based decision making.

Traditionally banks have employed silo risk systems to calculate the different types of risks such as market, credit, and asset and liability management risk. Risk aggregation to firmwide capital levels is then a post-process on the silo system's risk distributions or risk measures.

While the risk calculation itself is the core of a financial risk management system the system capabilities also rely on its risk infrastructure and what risk technology the system can use. The risk infrastructure should support the use of the system, for example, with proper workflows and configuration capabilities. The risk technology should be aligned to the requirements of the risk calculation. In many cases the development of the risk calculation algorithms and methods themselves must also take into account the risk technology to take full advantage of the computer resources such as processors and memory. In our discussion of the financial risk system's capabilities we will decompose the system capabilities into three components:

1. Risk analytics or risk calculation capabilities
2. Risk infrastructure capabilities
3. Risk technology capabilities

While we hope this book provides enough detailed discussion of the risk analysis methods to be successfully implemented in banks' current financial risk management systems, we would also like to give some explicit instructions on the core components to consider when constructing or implementing new financial risk systems. Indeed, constructing or implementing a new risk system is not a trivial task. Banks often face many competing challenges, such as a balanced decision weighing the trade-off between cost and performance, short-term and long-term needs, regulatory and internal compliance, security and new technology, and risk and finance reconciliation.

Risk Analytics

A risk system can be designed to only calculate (for example) market risk or can be designed more comprehensively to be able to calculate risk across many risk types. In general, a financial risk system implements a risk calculation flow where at each step in the flow risk analysts can assign or create new methods or models that are used in the risk analysis. Examples include pricing functions, market simulation models, and credit risk evaluation models. Many modern risk systems are designed to be comprehensive in the analysis of financial risk. That is, cover all the financial risks of a position that can come from market, credit, and liquidity risks. To accommodate the required risk analytics the risk calculation flow follows a few core sequential steps:

1. The calibration of risk factor models and joint scenario generation from risk factor models such as models for equity prices, interest rates, credit drivers, behavioral risk factors, etc. The scenario generation also includes the creation of ad-hoc stress scenarios.
2. The transformation of risk factors used in scenario models or ad-hoc stress scenarios to actual risk factors used for pricing and other risk calculations. For example, transformation of bond price and yield curve risk factors to zero-coupon curves used in pricing of cash flow instruments such as swaps, bonds, or loans. Other examples include currency triangulations for currency pairs that can be derived from existing currency pair scenarios, and factor models used for generating comprehensive risk factor scenarios from a core reduced set of macroeconomic risk factor scenarios.
3. The credit model rating assessment or probability of default calculation on instrument (loan), counterparty, or pool level needed to price or assign default and migration losses.

In case of credit model calculations on counterparty or pool level, all the associated pool or counterparty exposures inherit the credit characteristics.[8] The credit model rating assessment is conditional on the (credit) risk factors.
4. The pricing and cash flow generation of the financial instruments, conditional on rating model assessments and the market risk factors. The pricing and cash flow generation of traditional banking book instruments can also depend on behavioral risk factors such as deposit withdrawal behavior and prepayment rates.
5. Aggregation of pricing and cash flows and computation of relevant measures such as exposure. Aggregation examples include counterparty or netting set.
6. The application of collateral agreements or hedge strategies to reduce instrument-level exposures as well as aggregated exposure levels such as at counterparty or netting sets. Here, the collateral or hedge can itself be stochastic and depend on the risk factors and hence be priced in step 4 together with the exposures. Examples include market risk and liquidity hedging portfolios as well as credit collaterals such as mortgage property collateral and other collateral agreements with counterparties.
7. The application of risk and statistical summary measures on profit-and-loss results as well as on cash flows—for example, value at risk or other measures on profit-and-loss or traditional cash flow–based asset and liability management measures such as hedged and unhedged interest rate and liquidity gap.
8. The application of post-aggregation processing measures such as risk-adjusted returns that depend on the computed risk measures.

The eight steps in the risk calculation flow in a financial risk system are also illustrated in Figure 1.1. Of course, in this process we have assumed the necessary portfolio and market data are prepared for the models and the risk analytics. This process is not just pure data management but rather a joint effort between data and risk modeling teams to define a standardized risk data model.

Regulatory requirements and the fast evolution of market practices in risk analysis require risk systems to perform more and more risk calculations faster and faster, cover more risk

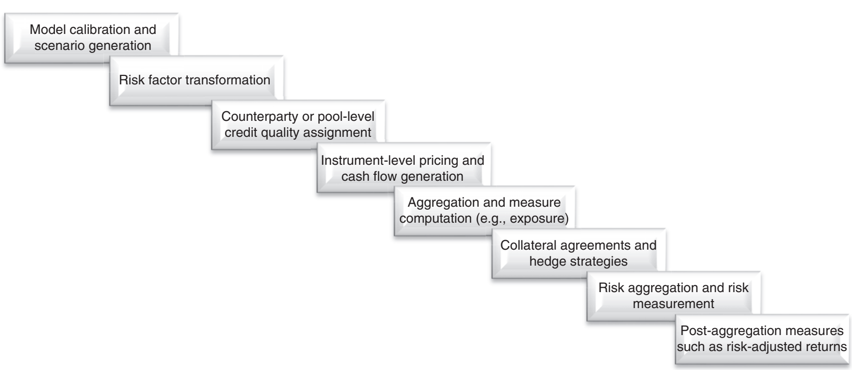

FIGURE 1.1 Risk Calculation Flow in a Financial Risk System

[8]In some cases a counterparty credit risk is also constrained by its parent entity credit risk. For example, a counterparty in a country is subject to the country risk and a subsidiary is subject to the parent company counterparty risk.

types (i.e., be more comprehensive), and be able to communicate results with other bank (risk) systems. For example, requirements such as CCAR and EBA stress testing exercises promote banks to analyze firmwide stress results in the context of impacts on projected future income statements and balance sheet statements. There can also be a feedback effect to the risk calculation when management actions are taken based on the projected income and balance sheet statements that affects the portfolios in the next risk analysis horizon.

Risk Infrastructure

Apart from the risk analytics and the risk calculation flow, a financial risk system needs a risk infrastructure. The risk infrastructure should both support the current use of the system as well as being able to adapt to future needs. We approach the requirements on a financial risk management systems risk infrastructure from a few core principles that the system should support. These core principles include:

- Comprehensiveness and relevance
- Accuracy
- Timeliness
- Governance
- Transparency
- Extensibility

The comprehensiveness and relevance principle means that the risk system must be able to capture all material risks that are in the scope of the system. That is, the system must have access to all the material risk data, by business line, legal entity, asset type, industry, region, and other groupings, as relevant for the risks in question. The system must also implement the risk models and analytics that are appropriate for the mission of the system, adequate to allow identifying and reporting risk exposures, concentrations, and emerging risks and adaptive to the granularity of the data. The data comprehensiveness should also encompass the multiple configurations the system is commissioned to do. Oftentimes a risk system has to be adaptive to multiple configurations even for a single risk type. Such configuration can be due to:

- Multi-jurisdictions that the institution has to respond to:
  This typically happens to a multinational institution that runs business in different countries or regions. Any international accord of risk regulation like Basel accords is subject to local modifications. Sometimes the modification can be quite significant due to the local business practice. In this case institutions have a choice to build different systems for different jurisdictions, which is not ideal for economic and integrity reasons, or have one system that can cater to different configurations on subset portfolios and economic data for the jurisdictions. A good example is the Basel II and Basel III regulations; many multinational banks that operate directly or indirectly through subsidiaries in very diverse regions face the challenge of being compliant with different jurisdictions. These international holding companies also need to aggregate and reconcile group risk measures to report to the group home regulators.
- Multiple business environments the institution operates in:
  Even for a non-regulatory risk analyses the need for multiple configuration settings can also easily come up because of different local business environments. First, different

countries have different governing laws that forbid a company doing certain things. For example, in the development and applications of the credit assessment models in some countries certain private customer information cannot be collected or used in the internal rating models even if the information is generally known as good predictors of the credit quality of customers. Another example is that the loan tenor can be different in different countries; some can be quite long (e.g., 30 years or longer) while the others can be short. Therefore, the analysis horizon can be of various length. Business calendars also vary across regions that call for different payment convention, pricing, and rate resetting models.

- Playpen, testing, and production:
  A risk system is not only designed to submit a set of final production results, but also needs to generate intermediate, testing, validation, and what-if results. Can the data and the system accommodate multiple sets of models, such as the champion and challengers? Can the data and the system sustain evolving regulations especially during the transition periods when different versions of the regulatory settings have to be accommodated?

Obviously accuracy is a key requirement for a risk system. Regulators and a bank's senior management must understand the risk profile of the bank in order to make informed risk-based decisions. Accuracy does not necessarily mean that every balance sheet and off–balance sheet item has to be evaluated or projected up to a certain precision. There are many approximation-based risk methodologies still actively used. However, banks must be able justify the validity of any approximation methods within the system.

The timeliness principle is related to the fact that risk analysis should reflect the current market situation and current portfolios to enable risk decisions to be taken on current risk information. With the important role of risk management in the value creation process in the banks, the delayed risk analysis is obviously not good for a bank to remain competitive. Meeting timeliness for a market risk application in trading book with frequent portfolio and market changes may require frequent intraday updates of risk while meeting timeliness for a credit risk application on the retail and commercial banking side may require less frequent updates due to relatively slowly changing portfolio compositions and credit conditions of borrowers. Timely analysis of a customer's risk profile, the bank's aggregated exposure to the customer, can help the bank to make a risk-based decision on customer retention and cross-sell and up-sell strategy based on the credit risk analysis and risk-based pricing. Timely monitoring of the bank's concentration, risk exposure, and cash flow projection in terms of regions, products, and currency can also help the bank to set optimal capital and liquidity hedging plans to proactively prepare for the possible downturn of the business.

A risk management process is not just about data and analytic results. The governance of the entire risk process is critical. A good risk system should therefore implement a workflow process that duly reflects the bank's risk governance policy. The workflow should clearly define the process and the staff's responsibility in the system. The same requirement also imposes security policies to the system. For example, when a data or risk analyst logs into the system, what kind of data and analysis does the analyst have access to? Another example is that not all the available data may be at the required quality for risk analytics. Banks usually have to approve the variables whose data can be used in modeling. The governance should also include approval and report submission workflows. When an analyst has a risk result ready the result should be validated and approved before reports are created and distributed.

Transparency is a core principle for a risk system. An analyst must be able to explain what the system does, including the data used, specific model assumptions, and risk calculations.

That the risk system is transparent is a key requirement for the bank to be able to understand the specific models and assumptions used in the system and hence to be able to validate them, either by data, expertise judgment, or both.

Connected to both the governance and transparency principles of the risk systems are critical requirements for a risk system to be able to trace, audit, and reproduce the results:

- Traceability means that the system provides a way to trace a result back to the right version of input in a particular incidence of a process. The scope of the traceability depends on how the user manages the input. That means the system should archive the inputs, including portfolio, market data, configuration, and models. Traceability also includes lineage. The lineage information can provide useful impact analysis results. The input data or a model parameter change lineage helps to trace which part of results or intermediate results would be affected. Another usage of lineage is to trace a risk result to see how it is attained.
- Reproducibility means that the system keeps enough information for the user to reproduce the same result when the user applies the exact same situation where the result of interest was created. Traceability is a prerequisite for reproducibility but the system has to now make sure all inputs are correctly restored and retrievable back to the system in order to reproduce the same input environment required by the result.
- Auditability for a system applies information in a shared data space in terms of who and what made changes to the system, and when.

Transparency, process, and governance are certainly critical to decision making. A decision must sustain questions, validation, and examination. Traceability, auditability, and reproducibility are obviously directly applicable. Risk-based decision making and performance analysis are in fact the ultimate purpose of risk management. In practice two categories of decision support are expected from a risk system. The first category of decision support is made almost completely by the system with minimal human intervention. Such decisions are usually based on well-established models and market practice. Decisions in this category can include automated approval/rejections of credit applications based on credit models and loan pricing models. Automated market-hedging strategies can fall into this category as well. The second system-generated decision support type is more referential and provides guidance to the decision makers. Accuracy and timeliness are two critical characteristics of a good decision-making framework.

Risk management is a quickly evolving discipline. This is not only because the methodology and technology change rapidly but is also due to the fast-changing economic and market environment in which banks are running business. The risk system should be adaptive to newly identified risks, new methodologies, and new reporting requirements. For example, during the Greek debt crisis, global and European banks were demanded to submit their total exposures to Greek counterparties and a few other European countries that had similar debt size concerns to the senior management and regulators. It turned out to be a difficult task for many banks. This was because the aggregated risk to such a level was never calculated and reported before. If a system cannot support quick extensibility, it will not only induce more operational cost and risk at the time of the new risk analysis requirement but also disable the accuracy and timeliness of the risk analysis.

Risk Technology

The proper use of the technology is key to financial risk systems and the actual implementation of the quantitative methods discussed in this book. It is also decisive for meeting the timeliness principle we discussed in the context of risk infrastructure. Just as any computer system, a risk system faces the constraint of four major computer resources:

- Processor capacity
- Memory capacity
- Storage capacity
- Network bandwidth in distributed calculation and storage on a grid of multiple computer nodes

The first obvious way to reduce calculation time for a risk analysis is to deploy the risk calculation on parallel processors. However, the first challenge is to ensure that the algorithm itself, if possible, is not deployed as a sequential calculation. Parallel programming can in principle be achieved even in this case if multiple such algorithms can be executed simultaneously. Many portfolio risk analyses are naturally deployed in parallel. For example, the pricing of positions can be done independently across a set of scenarios. For a fixed number of processors the optimal distribution of exposure valuation to processors may depend on the analysis type. For example, for many scenarios such as a model simulation it may be optimal to distribute the scenarios while for just a few scenarios such as a stress test it may be optimal to distribute the positions. Even so-called nested simulation pricing methods, where simulation is used to price the position for every risk scenario, can in principle be distributed. This is because, for a given risk scenario, the nested simulation position can be distributed in sub-positions with independent, smaller, nested simulation samples that are eventually aggregated to an average nested simulation price for the position.

The parallel processing can also be more complex to implement. For example, in credit risk applications one frequently needs to first calculate the credit quality of the counterparty, then price the exposures belonging to the counterparty, aggregate exposures, and then allocate the collateral to the exposures. That is, perform steps 3–6 in the risk analytics flow in the financial risk system discussed above. The easiest solution is to distribute by counterparties and hence by all the exposures and collateral belonging to a counterparty. However, such a distribution approach may not be optimal as the pricing time for counterparty exposures may vary significantly, either due to portfolio size, pricing complexity, or both. While distributing exposures with one single counterparty onto different computer threads may result in simultaneous access to the counterparty data the independent exposure evaluation may still be optimal. Of course, in this case, at the time of collateral allocation the counterparty exposures and priced collateral on different threads may need to be aggregated back. This is one example that calls for full understanding of the analysis sequence when designing the parallel computation.

Processing capacity is not the only constraint. The second is on the memory. Faster processing time achieved through parallelism increases the demand on memory. Individual machines can only have a certain amount of memory. When the risk calculation requires many more folds of memory for the input and intermediate data, increasing parallel processing will run into the obstacles of memory requirement. For this reason traditional systems constantly upload and unload data between memory and the hard disk, which can create a lot of bottlenecks. Writing and reading information to and from the storage trades off with the memory usage. However, the introduction of grid computing makes available not only more processors but also memory from a cluster of multiple computers. Holding data in memory and not writing it to disk can avoid the writing and reading bottlenecks. This in-memory technology can be applied not only to a system with complicated calculation logic but also to systems for large-scale query of risk results. Holding the lowest level of risk data in memory, such as profit and loss per position for every scenario, makes the risk system more flexible in terms of the risk measures and risk results that can be queried on demand. Because memory is not an unlimited resource, it is imperative to optimize the implementation of an algorithm to decide what information should be held in memory for fast access and what should be written to the storage and release the memory for that information.

Storage technology has also vastly advanced just as the other computing resources. Now it is not difficult to find hard drives that can hold terabytes of data but even this size on one single computer can easily be obsolete for a risk system. In contrast to the traditional direct storage to each individual computer, network storage has become the standard for many risk systems. However, it is not necessarily optimal for the application if a large volume of data is required within a short period of time (i.e., high data velocity). There are a couple of solutions to high velocity. The first is through a high-velocity, low-latency data event stream processing technology; the other is to leverage a distributed file system. Both solutions are mostly applicable to a grid computing setting where a large number of computer nodes are available for an application. A risk application can interact with data storage in several ways. Traditionally, risk systems require data to physically move out of the storage for input to the risk analysis, and also later to physically move the risk results to storage for subsequent reporting. The physical movement of data not only can be time consuming but can also create unnecessary staging data copies that can quickly fill the storage. Another approach for risk systems to consume and deliver data is to leverage in-memory. In-memory views of data can in principle also include transformations. The benefit is the potential speed of data delivery and that a physical duplicate of data is prevented.

Another factor that affects the choice of distributed calculation and storage on a grid of multiple computer nodes is the network bandwidth. Network bandwidth is a scarce resource even when a dedicated network is set up for the grid. Nowadays multigigabytes of data can be transmitted among computers. However, oftentimes multiple nodes share one network cable. If a lot of data are transmitted through the network, it can easily saturate the network bandwidth capacity. Therefore, one should consider the network factor in risk system architecture.

MODEL RISK MANAGEMENT

Risk analytics is the core of a risk system. It is also this book's focus. In a book that focuses heavily on risk analysis models it is appropriate to discuss model risk management even before going into detailed discussion of any models.

A risk system contains many different models used in the risk calculations. Models have their lifecycles and need to be frequently validated and tested. The need for more risk calculations and their growing complexity also means that banks need to manage and validate more and more models that are deployed in the risk system(s). Sometimes models are managed on a firmwide level even if certain risk calculations are executed on a silo risk system level. A firmwide model risk management approach is motivated by the firmwide stress test requirements from CCAR and EBA. Given the many different models that are involved in banks' regulatory calculations, banks' practice in model risk management is also a serious concern for regulators. For example, in 2011, the US Federal Reserve and the Office of the Comptroller of the Currency (OCC) issued joint guidance on model risk management practices.

Model risk can arise from many points in an analytical risk process. It cannot be completely avoided but it can be managed. Model risk can arise and thus ought to be managed in the following aspects:

- Model data:
  The first source of model risk is data. We are familiar with the garbage-in-garbage-out rule. When the input data have major flaws, even the best model can generate misleading results. Data flaws can occur not only due to the data quality but also from a partial selection of the data history. For example, in the years preceding the 2007 financial crisis, housing price statistics displayed upward trending for many years with only sporadic default losses. When banks used this part of the historical data in the housing price models and the credit default risk models it was impossible to obtain tail risk levels anywhere close to the losses in the 2007 financial crisis. Even if data are available that cover a full business cycle with both up- and downturns it is still just *one* observation of a business cycle. The future business cycle swings will most likely not be similar to the last one. This observation is relevant not only in the context of using data for model calibration such as how probability of default depends on the business cycle but also in selection and design of (macroeconomic) stress scenarios for the portfolios.[9] Another well-studied data flaw subject in the econometrics literature is the survivorship bias, which leads to overly optimistic beliefs of the future. Therefore, in many institutions there is strict governance on the data that can be used for model development and application.
- Model assumptions:
  A famous quote from Box and Draper (1987) is, "All models are wrong; the practical question is how wrong do they have to be to not be useful." Every model is an approximation. In order to reach a parsimonious view of the world but still remain useful proper assumptions have to be made. First, it is important that the assumptions are practically reasonable. Second, when the model is applied the model assumption should still hold. Of course, the readers of this book are urged to understand the assumptions of the models presented in this book and validate the model assumptions against the specific application purpose when a model is adopted.
- Model development:
  There are many examples in this book where models are developed with clear assumptions and sound economic and mathematical theory. These are the foundations of a good model. As mentioned before, the design and choice of a model must fit the actual use case. Therefore, the model development is a collaborative work between model developers and the business experts. Testing the fit of a model is also an integral part of the model development. However, good model fit on historical data is not necessarily a good indicator that the model will be able to generate relevant future risk scenarios. Good model fit should be complemented with expert judgment. A model with less statistical fit may outperform as a risk model. When fitting models it is also important to be prudent in what history is chosen for the model fit. Model parameters estimated on data can also be overridden with more prudent estimates. Because of the changing business environment a model is always subject to reexamination, redevelopment, and revalidation.

[9]It is a relevant question to ask if a model that has been calibrated over a specific business cycle can be confidently used to predict behavior in other types of stressed tail events.

- Model documentation:
  The Basel 2005 document explains the assumption, insight and derivation of the Basel II risk weight functions for the internal model–based approaches (Basel Committee, 2005c). This document also sets a good example of model documentation. Every model employed in a risk system should be clearly documented for its assumptions, economic insights, mathematical justification, and reasons to be adopted for a particular risk analysis. Besides these elements, it should also document the history of the model updates to give information on how a model has evolved. Other information related to model governance such as developer, modification date, version number, and so on can also be included in the model documentation. A model document not only helps explain the model to the stakeholders, including the regulators and senior management, but also allows better transition of the model knowledge when there is any staff change. The latter is important because it warrants the continuation of the knowledge of the model.
- Model validation:
  Model validation is getting more and more attention in the financial institutions. Independent validation groups are established to examine the models from assumption all the way to production. There are several tasks a model validation function is responsible for. The first is to examine the key elements of a model as discussed above. Second, the model validation group applies statistical tools to validate the model outcome. On some occasions the model validation function also creates overlapping models to cross-check the developed models. The validation group can also check the computer programs and the documentation of a model. Techniques familiar to mathematicians and statisticians are widely used in model validation. For example, pricing models and the parameters are constantly calibrated to the market values and peer models. In-sample and out-of-sample performance tests are performed on the statistical models and risk measures are backtested. In many cases, champion and challengers models are set up in the model repository to diversify model risk and enhance the governance. This book contains several examples of model validation, especially on backtesting. One example is the backtesting study of the time aggregation of market risk with and without trading, which challenges the regulatory time scaling risk approach for the market risk capital.
- Model execution:
  All the models are created to be used. Therefore, model execution usually is the last step in a modeling process. This stage is where all the models are put together to accomplish a certain risk analysis. The prerequisite of this stage is to make sure required data and assumptions of the model are suitable. This is when the data, the analysis of interest, and model assumptions must be aligned. A common source of model execution risk is the loss of fidelity when models are translated from the model development platform to the model execution platform. It is not unusual for banks to have models in actual use being several versions behind the models just developed. Another challenge in this stage is whether the system can efficiently accommodate the sophistication of the models. Such sophistication includes both the mathematical complexity and the granularity of the data the model applies to. For example, a bank that moves from a pooled analysis of banking book credit losses and cash flows to loan level models not only faces the challenge of more granular model validation. This increased granularity requires the risk system to be able to execute models against millions of loans. The capturing of credit losses and cash flows over long horizons leads to challenges in computer processing, memory, input and output capability, as well as storage. To solve this challenge, banks must find balance between the efficiency of the risk system and the models to be used.

- Model governance:
  There is rarely a case that one risk system actually carries out all the modeling functions covered in this section. Sometimes these functions are dispatched in different systems. For that very reason model governance becomes essential to minimize the model risk in the entire modeling lifecycle. Although model execution is usually the last stop in a modeling cycle, it should not be the end of the process. The result of model execution should be validated and serve as a trigger for model updates. To minimize the model risk, it is preferable to automate the entire model risk management workflow. This workflow typically requires a clear management policy in terms how a model, from its inception and development, can finally get into the production and participate in any risk analysis. Rigorous examination and approval should be put in place. A good model governance capacity should also be able to track all the issues and actions about all the models in its specific usage, for example, all the stress testing models or market risk capital models. When the model validation team discovers an issue, they should be able to track who owns the issue, what is the current status, and if/how it was resolved.