Enterprise Credit Risk Management

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Credit risk comes in many different colours, styles and shapes, and is traditionally managed strictly in silos. This introduction motivates the development of a framework for integrating credit risk and reward across the enterprise and describes its necessary components. Four fundamental modelling requirements are emphasized: the simultaneous use of various credit risk models; the accurate modelling and valuation of individual credit risky instruments; the integration of market and credit risk; and the construction of effective tools not only to measure risk, but also to manage and optimize risk and reward. We present the Mark-to-Future framework as an effective solution to these substantial objectives.

Credit risk has become one of the central topics in risk management today. The last decade has seen substantial research on practical models to support obligor creditworthiness assessment, pricing of credit risky instruments, measurement and control of credit exposures and analysis of portfolio credit losses. With estimates that loans, corporate bonds and credit derivatives together account for more than 30 trillion in US-dollar exposures worldwide, improved credit risk management techniques have the potential to provide enormous business benefits.

While substantial progress has been made in solving certain aspects of the credit risk management problem, the development of a consistent framework for managing the various sources of credit risk in an integrated way has been much slower. Even the most sophisticated financial institutions have yet to integrate the disparate components of credit risk that are needed to support consistent risk and reward management on an enterprise-wide basis.

The reasoning behind this lack of a true enterprise solution is not hard to understand; credit risk comes in many different colours, styles and shapes, and is traditionally managed strictly in silos. The sources of credit risk are remarkably diverse: from corporate and sovereign bonds to credit derivatives and over-the-counter derivatives such as interest rate swaps; from syndicated loans, middle market and small business commercial loans, to retail mortgages and credit cards. Furthermore, credit risk has been traditionally managed separately from market risk, which has led to the emergence of two different "cultures" within a financial institution.

However, the competitive environment for financial institutions is rapidly changing. The advent of credit derivatives and structured transactions is providing a more efficient transfer of credit risk. Furthermore, the loan and bond markets are maturing and show signs of continued convergence. Thus, the assumption that credit risk cannot be managed actively is seriously being reconsidered. Although a market-based valuation and assessment of credit risk is not yet a widespread practice, both industry

best practices and regulatory trends are pointing strongly in that direction. Finally, technological advances now provide ready access to non-traditional institutions and investors in the credit markets and allow the application of sophisticated computational tools to price and manage credit risk.

In today's increasingly integrated financial markets, managing in silos is not satisfactory, and financial institutions are compelled to manage the risk in the banking and trading books in a more unified manner. The major business benefits of implementing an enterprise-wide framework for measuring, controlling and managing credit risk include:

- improved credit risk transfer pricing between the origination and portfolio management functions
- reduced credit losses and credit value volatility
- enhanced liquidity of credit risky instruments that leads to better trading and hedging decisions
- more effective management of regulatory and economic capital
- more efficient allocation of credit risk capital through clear comparability of various business opportunities
- greater credit risk transparency for both shareholders and regulators
- increased internal leverage of people, systems, methodologies and data.

Thus, the development of an enterprise-wide credit risk framework has become a key strategic objective for financial institutions entering the new millennium. This framework must recognize obligor diversity and accurately capture credit instrument complexity. It should facilitate the integration of various, often complex, sources of credit risk through multiple models. It must also naturally allow for the integration of market and credit risk, as it becomes increasingly inefficient to manage these risks independently.

In the end, the key goals of an enterprise credit risk framework are to present an integrated picture of the risks incurred across a financial institution, as well as to provide consistent decision support tools to manage the risk and return. In a bank, enterprise refers to both the banking book and the trading book, covering various business lines, diverse products and customer markets (see Figure 1). In some cases, credit risk is a by-product of the market risk undertaken in the trading book by actively trading bonds, derivatives such as swaps and forwards, and credit derivatives. In other cases, such as the traditional lending businesses, it arises from actively originating, servicing and funding corporate loans or supporting retail-lending operations.

Enterprise credit risk

Figure 2 shows the four key functions of an enterprise credit risk framework. Credit risk analysis starts with an assessment and quantification of an obligor's credit quality. Next, it is necessary to model accurately individual credit risky instruments, in order to value them properly and understand their risk. Then, the first step of portfolio credit risk analysis is to obtain a consolidated picture of the exposure that results from all the transactions with a given entity or within a given sector. Generally, credit risk controls are implemented around these exposure measures. The final goal is the measurement and management of credit risk capital based on a consolidated analysis of all obligors and credit positions within an enterprise portfolio.

In what follows, we give a brief description of each function. Parts one through four in this volume elaborate further on these functions and present several papers that showcase their practical application.

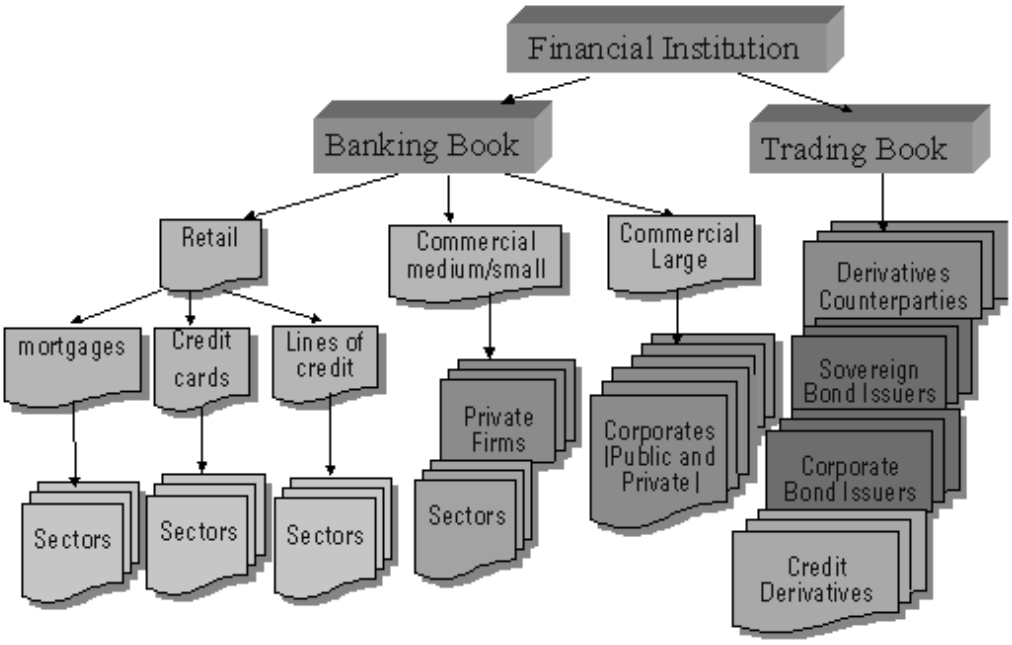

Figure 1: Enterprise view of credit risk in a bank

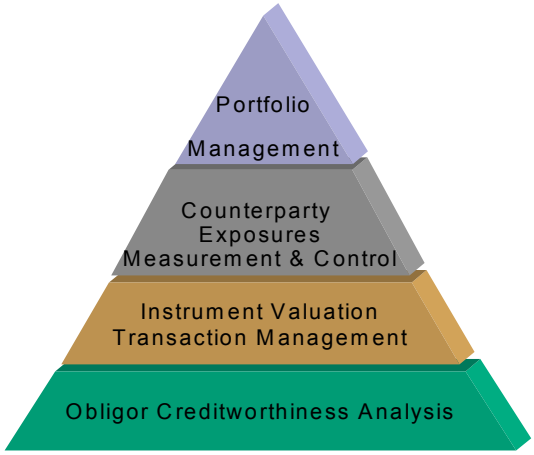

Figure 2: Enterprise Credit Risk Functions

Obligor creditworthiness assessment

A credit risk analysis begins with an assessment of obligor credit quality. As shown in Figure 1, a financial institution generally deals with several different types of obligors: sovereigns and local government institutions, large public firms, large and midsize private firms, small businesses and start-up companies, and retail customers. Obligors have different characteristics, and their creditworthiness is affected by different economic circumstances—a single model cannot fit them all. An enterprise credit risk management function must provide a framework in which the different models required for assessing obligor creditworthiness can be used simultaneously to obtain an overall picture of risk.

Within an enterprise credit risk framework, the obligor creditworthiness assessment function produces three main quantitative outputs:

- obligor default and migration probabilities
- facility recovery rates (or loss given default)
- credit event correlations.

We briefly explain each of these below.

Traditionally, the credit assessment often starts with a *classification* of the obligors and a *quantification* of their ability to fulfil future obligations. This results in credit ratings, which provide an ordinal measure of default risk, as well as estimates of default and credit migration probabilities.

An enterprise credit risk framework requires various creditworthiness methodologies to evaluate each different type of obligor. These methodologies include:

- consumer models and bureau scores in retail sectors
- agency ratings for firms, sovereigns and government institutions, which have rated debt
- public firm models that, through option theoretic approaches, use equity markets information as a key input
- private firm models, based on statistical analyses of balance sheet and income statement information
- subjective and qualitative methods for firms and markets where not enough reliable information is available.

The assessment continues with an evaluation of the obligation. A key objective of this step is to obtain a picture of possible losses in the event of default, expressed generally as recovery rates or loss given default. Generally, estimation of recoveries is based on statistical analyses of historical default experiences for different types of seniority and degrees of securitization.

The creditworthiness of obligors may depend on external systemic conditions and, hence, obligor credit events can be correlated. Credit correlations are required to price accurately instruments with multiple obligors such as baskets, collateralized debt obligations (CDOs), and even standard derivatives (such as swaps or forwards) and credit derivatives. Correlations are also a key input to portfolio credit risk measurement. Thus, the creditworthiness assessment must also provide a quantitative measure of the codependence of possible joint obligor credit events. Generally, it is practical to use multifactor models to explain this codependent structure in terms of *systemic* factors, or *credit drivers* (such as macroeconomic factors, industry and regional indices, etc.), and *idiosyncratic components*. In this way, linking different credit models for different obligor sectors in an enterprise credit risk assessment can be achieved by modelling the joint behaviour of the credit drivers influencing joint credit events in each sector.

Valuation of credit risky instruments

Valuation is at the heart of a risk management framework and it builds directly upon assessments of obligor creditworthiness. An enterprise credit risk framework requires a variety of pricing tools to model the myriad credit risky instruments: bonds (corporate, local government and sovereign); loans and lines of credit (commercial and retail); OTC derivatives such as swaps or options; and credit derivatives such as default swaps, total return swaps and spread options; and structured products such as CDOs.

No-arbitrage pricing is the basis for pricing and hedging securities, for marking-to-market portfolios, as well as for measuring and managing financial risk. It allows the comparison of instruments with different structures; the pricing of complex instruments consistent with the observable prices of simpler or more liquid instruments; the design of effective hedging strategies and the exploitation of possible price discrepancies or arbitrage opportunities.

The development of practical valuation techniques for instruments bearing credit risk has received substantial emphasis in traded markets. Although not yet a widespread practice, Mark-to-Market valuation has only recently stepped to the forefront of the credit risk management agenda in the more traditional credit markets, where banking-book loans generally have complex structures and embedded credit options. This has occurred in response to competitive business pressures, enhanced secondary loan market liquidity, rapid growth in structured products (CDOs) and evolving regulation.

The application of better credit risk valuation models for the loan book supports several important objectives:

- Valuation provides the key risk-reward metric required to manage more proactively credit risk at loan origination. The process of loan origination has been, for the most part, a passive activity. However, with better information on the value of implicit structural trade-offs, lenders can proactively originate loans that satisfy internal risk/reward objectives and exploit potential arbitrage opportunities from structural features, while offering greater flexibility for customers.

- Valuation is the basis of consistent measurement and management policies across the trading and banking books. Pricing models calibrated to more liquid, traded instruments in the market provide an infrastructure for comparing "apples to apples" and making better capital allocation decisions.

- Valuation also plays a key role in portfolio management and credit Value-at-Risk analysis. Economic credit capital should be based on Mark-to-Market models and several portfolio credit risk models are now beginning to recognize this.

Counterparty credit exposure measurement and control

The first level of portfolio credit risk analysis is to obtain a consolidated picture of the exposure that results from all the transactions with a given entity. Often, this is a major systems exercise that entails the collection of all positions with that entity (regardless of the instrument type, system or geographical origination), the application of existing netting and credit mitigation agreements, and the management of collateral.

Derivative desks and commercial operations traditionally manage credit risk by monitoring and placing limits on counterparty credit exposures at different levels. Although exposure is only one component of credit risk (the other components being the probabilities of default and migration, recovery rates and correlations of credit events), it is generally seen by practitioners as a simple and actionable measure. Therefore, it is a central component of the credit risk control systems used by financial institutions today.

Counterparty exposures of derivatives such as swaps or forwards depend on the level of the market. Thus, it is vital to measure both the actual exposure and its potential future changes. The current BIS regulatory model computes potential exposures through a simplistic add-on factor that multiplies the notional of each transaction. Although simple to implement, the model has been widely criticized because it does not accurately account for the stochastic nature of these exposures in the future. Many attempts have been made by practitioners to develop more sophisticated add-on methodologies. However, it is now widely recognized that one cannot obtain an add-on model that is simple and general enough for practical implementation.

In recent years, financial institutions have started to implement advanced simulation methods to compute counterparty exposures, which accurately capture their stochastic nature, as well as the richness and variety of netting agreements, collateral behaviour and mitigation techniques used in practice. Accordingly, many practitioners are pushing for regulation to allow these methods to be used as the basis of regulatory capital calculations. In the end, accurately measuring counterparty exposures requires an integrated market and credit risk methodology. Such a methodology can also address important problems such as:

- wrong-way exposures, where exposures are correlated to credit events such as default
- roll-off risk, where short lived exposures arise from the maturity of a position hedging another position with a longer maturity
- settlement risk, which deals with the exposure of actual cash flows not being received when they come due.

Portfolio credit risk measurement and management

A portfolio credit risk analysis focuses on computing the credit capital of aggregate portfolios of credit exposures, specifically capturing the correlations between obligor defaults and migrations. As the culminating step in managing enterprise-wide credit risk, a portfolio credit analysis must successfully integrate all of the previous enterprise credit functions: obligor creditworthiness, valuation and counterparty credit exposures.

To support an enterprise credit risk framework, a robust portfolio credit risk solution must provide:

- **Enterprise credit risk measurement**. It must recognize the diversity of obligors across the enterprise and, thus, provide a framework that allows for the simultaneous use of several models, which are best suited for each type of obligor, and a flexible modelling structure of obligor correlations.
- **Instrument valuation**. Credit portfolio losses arise from changes in the values of the securities held in the portfolio due to credit events. Credit risky instruments range from bonds to loans, from OTC derivatives to credit derivatives and collateralized debt obligations. Precise modelling of each credit risky instrument is vital for its accurate valuation and the computation of credit capital.
- **Integration of market and credit risk**. The proper integration of market and credit risk is vital for valuing many instruments (including loans), computing counterparty exposures, accounting properly for collateral and mitigation, and for estimating portfolio credit risk. Although not yet common practice, it is rapidly evolving into an unavoidable requirement as the practice of trading credit-risky instruments and derivatives becomes more widespread, and as portfolio management is evolving into a dynamic function. In particular, the integration of market and credit risk also has a substantial impact on measuring issuer risk or specific risk for bonds, and is the key requirement to understand and manage wrong-way exposures.
- **Effective risk management tools**. In addition to monitoring risk, an effective risk management function must help the firm understand the sources of its exposures, how market or portfolio changes affect its risk profile, and how to obtain optimal risk versus return trade-offs within *and* across various business lines. However, in credit risk applications, these tools can not be based, as they have been traditionally, on the standard normality assumptions of Modern Portfolio Theory (MPT).

In addition to these four key deliverables, an enterprise portfolio credit risk framework must provide the ability to measure and manage both *economic* and *regulatory* capital. Although the new proposal for

banking regulation by the Basel Committee (Basel Committee on Banking Supervision 2001) is a step closer to aligning the two, it still does not allow for internal portfolio models to drive the calculation of minimum capital requirements. Since regulatory and economic capital may differ substantially, the enterprise portfolio credit risk function can effectively help reconcile economic and regulatory capital and their contributions, explain their differences, and provide management strategies to exploit those differences and manage the business more profitably.

The evolving business model for portfolio credit risk is moving from the traditional "originate and hold" approach for credit risk to an "efficient portfolio" approach. As the portfolio management function becomes a profit and loss center, front-office originators of risk-inefficient loans are no longer finding unlimited appetite for keeping the assets in portfolio. On an enterprise-wide basis, mark-to-market valuation is rapidly becoming a key component of credit risk transfer pricing between the front-office originators and the middle-office portfolio management function.

Within the last few years, a number of first-generation portfolio credit models have been popularized in the industry, including J.P. Morgan's CreditMetrics, Credit Suisse's CreditRisk$^+$, McKinsey's Credit Portfolio View and KMV's Portfolio Manager. While all of these models have constituted important advances in our ability to understand and model credit risk, each of them in isolation does not provide a solution to the four key deliverables required for measuring and managing enterprise credit risk.

A second-generation credit risk methodology must incorporate the best characteristics of each of these models to provide a comprehensive enterprise solution. This solution must consolidate credit risk across the entire institution, integrate market and credit risk, and provide a set of tools for managing credit risk and trading off risk and reward efficiently.

The next section discusses how Mark-to-Future (MtF) constitutes a powerful, simulation-based, second-generation enterprise credit risk management framework that provides the four key deliverables mentioned earlier. Further details on the MtF framework can be found in the technical document by Dembo et al. (2000) and throughout this volume.

Mark-to-Future framework

At the heart of every credit risk decision is an assessment of the inherently uncertain value of an instrument subject to credit risk at one or more future horizons. Simulation-based methods can accurately model this uncertainty by assessing market and credit risk across a range of future potential outcomes, or *scenarios*. Decisions to trade, originate or hold credit-risky instruments can be based effectively on the risk and reward trade-offs obtained from a simulation analysis.

Mark-to-Future is both a robust and forward-looking *framework* that integrates disparate sources of risk and reward, as well as an open and extensible risk *architecture* that can be leveraged within a single organization and across several organizations.

The MtF framework provides a flexible and unifying platform for assessing future uncertainty by explicitly incorporating the passage of time, the evolution of scenarios and the dynamics of portfolio holdings over time. Furthermore, by using scenarios as the drivers of future uncertainty, Mark-to-Future is an intuitive framework that facilitates communications across different business lines. Scenarios become the language of risk.

As a risk architecture, Mark-to-Future enables the decoupling of the computationally intensive simulation stage (the risk service) from the post-processing risk/reward assessment stage (multiple-risk clients). Simulations need only be performed once and the results can then be distributed across multiple applications. Mark-to-Future also accommodates differing views of what the future may bring, and different models for pricing assets and positions, now and in the future.

Mark-to-Future for integrated enterprise market and credit risk management

Mark-to-Future provides an efficient second-generation enterprise credit risk solution. As a multi-step simulation framework, Mark-to-Future recognizes that risk and reward measurement requires accurate instrument valuation, not only at the current time, but also at various future horizons.

The use of scenarios naturally allows the integration of credit risk across the whole institution through the simultaneous use of various creditworthiness models for each kind of obligor, as required by the first enterprise credit risk function described earlier. It also accommodates various accurate pricing models of credit risky securities, as required by the second function.

In Mark-to-Future, scenarios are also the basis for integrating market and credit risk. By directly modelling stochastic exposures, collateral and recovery rates, Mark-to-Future properly models exposures caused by instruments with embedded derivatives, thereby overcoming a major limitation of current portfolio models. Furthermore, through the explicit modelling of default/migration probabilities conditional on the state of the economy, the framework also serves as the basis for accurately estimating wrong-way exposures. Finally, Mark-to-Future provides a set of scenario-based tools for managing credit risk and trading off risk and reward efficiently.

At the core of the MtF framework is the generation of a three-dimensional *MtF Cube*. To build the MtF Cube, a set of scenarios is chosen. A **scenario** is a complete description of the evolution of key risk factors over time. In the case of credit risk, a scenario defines explicitly the joint evolution of market risk factors and credit drivers. **Market factors** drive the prices of securities, and **credit drivers** are systemic factors that affect the creditworthiness of obligors in the portfolio. Thus, risk factors are general and can be microeconomic, macroeconomic, economic and financial variables. Note that in most risk implementations, a distinction is made between "typical" market conditions and extreme scenarios used for "stress-testing." In MtF, both types of conditions are handled in the same manner, through scenarios.

Using the specified set of scenarios, a *MtF table* is then generated for a given financial instrument or obligor. In the simplest case, each cell of the MtF table contains the computed MtF value for that financial instrument under a given scenario at a specified time step. More generally, each cell of a MtF table can contain a vector of risk-factor dependent measures for a given instrument or obligor, under a given scenario and time step. A **MtF Cube** consists of a set of MtF tables, one for each financial instrument. Figure 3 illustrates a representative MtF Cube. In credit risk applications, the MtF Cubes may store MtF values of instruments, credit drivers, obligor creditworthiness indices and conditional default and migration probabilities.

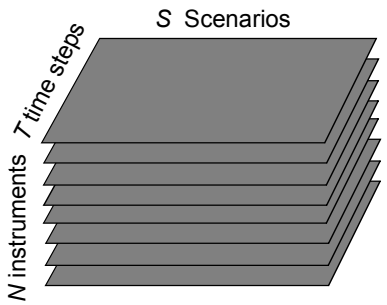

Figure 3: Representative MtF Cube

Key to the MtF framework is the premise that knowledge of portfolio holdings is not required to generate a MtF Cube: a single MtF Cube accommodates the risk/reward assessment of multiple portfolios simultaneously. In essence, for any given set of holdings, a portfolio MtF table can be created

simply as a combination of the MtF Cubes with the values of all individual instruments and obligor creditworthiness. This **portfolio MtF table** contains the values of the portfolio over every scenario and time step. Thus, risk/reward analyses for any set of holdings can be seen as general post-processing of MtF Cubes. For example, the marginal risk/reward assessment of a given position can be computed by changing the number of positions and mapping the MtF Cube into the new portfolio.

The MtF framework for integrated market and credit risk was first described in Iscoe et al. (1999), (and is also reproduced in Part Four of this volume). It combines the main ideas to reconcile first-generation portfolio credit risk models in Koyluoglu and Hickman (1998) and Gordy (2000), with multi-step simulation techniques for market risk and counterparty exposure estimation. The framework can be expressed in five steps (see Figure 4).

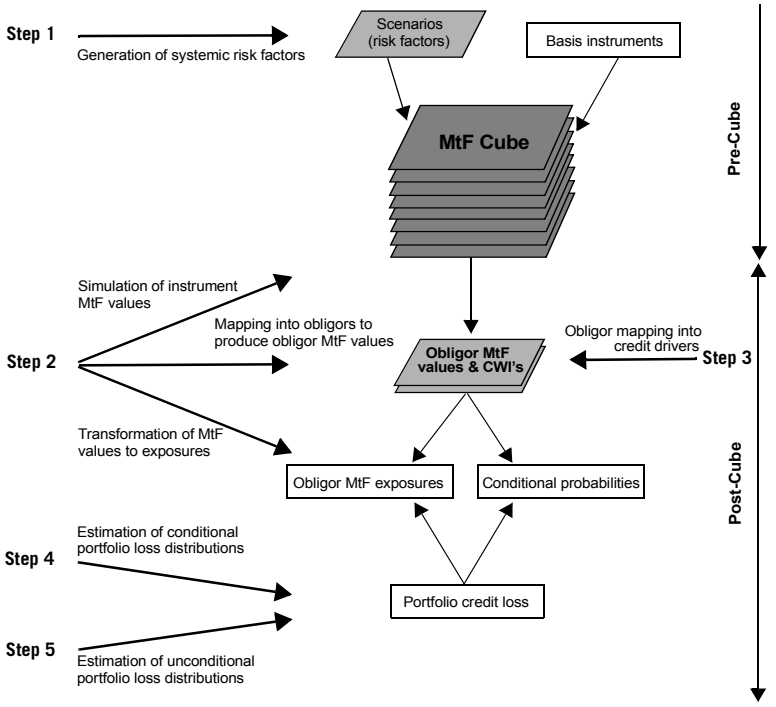

Figure 4: MtF framework for integrated market and credit risk

Step 1: Scenario generation for risk factors. Scenarios are created, which explicitly define the joint evolution of all the relevant systemic risk factors over the analysis period. Risk factors include both market factors and credit drivers.

Credit risk applications require the generation of scenarios over long horizons, sometimes up to the maturity of all outstanding positions. Since the values of many instruments such as derivatives and even bonds and loans are very sensitive to prevailing market conditions, the assessment of counterparty credit exposures may generally require scenarios on all market factors affecting their values. Portfolio credit risk also requires that the scenarios describe the states of credit drivers, which influence the financial health of all obligors. For example, these factors may be country, region and sector indices that affect the asset value and credit quality of each obligor.

By describing the joint evolution of these market factors and credit drivers, the integration of market and credit risk is thus achieved in the scenarios.

Step 2: Obligor exposures, recoveries and losses. The amounts that will be lost in the event of a default or credit migration are computed under each scenario. Based on the level of the market factors in each scenario at each point in time, MtF exposures for each obligor are obtained accounting for

netting, mitigation and collateral. Similarly, recovery rates in the event of default can be scenario dependent.

To compute obligor exposures, first the MtF cube with the value of all instruments is obtained through simulation over the chosen scenarios and time steps. Then, in a post-processing step, the credit exposures to a given obligor are obtained by aggregating all the transactions with that obligor, applying any netting agreements, collateral and credit mitigation. This process is depicted in Figure 5. Note that this step produces the necessary counterparty exposure measures that may be used for the limits management function.

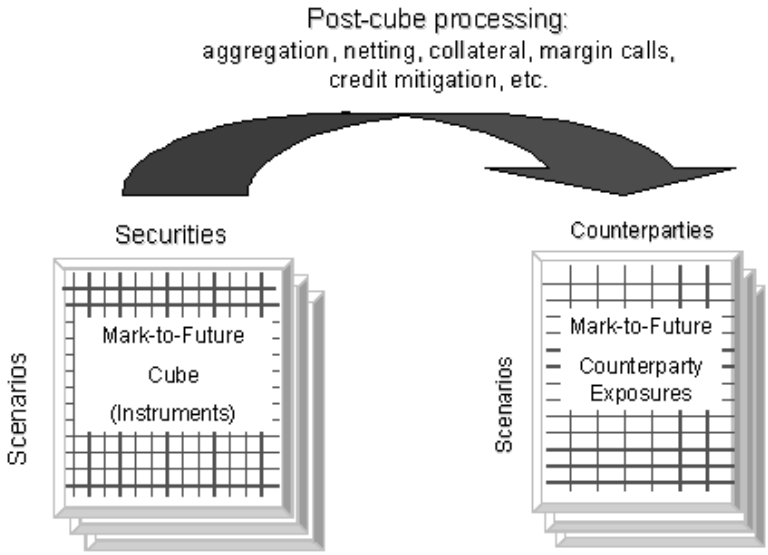

Figure 5: Counterparty exposures in MtF

Step 3: Joint default/migration. Default and migration probabilities may vary as a result of changing economic conditions. Thus, an obligor's default/migration probabilities are conditioned on the scenario path up to each point in time. Correlations among obligors are determined by the joint variation of conditional probabilities across scenarios.

It is natural in many practical applications to express the relationship between the conditional probabilities and the levels of the credit drivers through an intermediate variable, called the obligor's creditworthiness index (CWI), which represents the financial health or value of the obligor. In this case, a default/migration model defines the functional relationship that maps the CWI and the *unconditional* default/migration probabilities into *conditional* default/migration probabilities for each scenario and time step. As depicted in Figure 6, various credit default/migration models can be used simultaneously for different types of obligors, which is an important requirement for managing enterprise credit risk.

Step 4: Scenario conditional portfolio loss distributions. By applying steps one through three, one obtains the credit losses as well as the likelihood of these losses for each obligor in a portfolio, conditional on a scenario. Computation of conditional portfolio losses can then be computed by combining all of these through a mathematical operation called convolution. In practice, the computation of these conditional portfolio losses can be onerous. In the most general case, a Monte Carlo simulation can be applied to determine conditional portfolio losses. However, conditional on a scenario, obligor credit events (defaults and migrations) are now independent. This observation permits the application of effective computational tools.

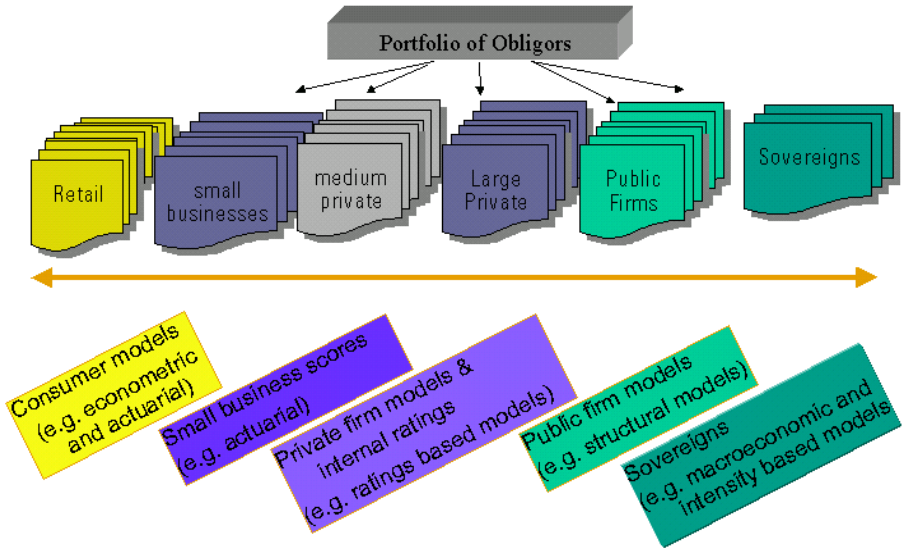

Figure 6: Obligor creditworthiness models for conditional credit event probabilities

For example, for a very large, homogeneous portfolio, the law of large numbers can be used to estimate conditional portfolio losses. Other methods include the application of the central limit theorem (which assumes the number of obligors is large, but not necessarily as large as that required for the law of large numbers), the application of moment generating functions with numerical integration or the application of probability generating functions with a discretization of exposures.

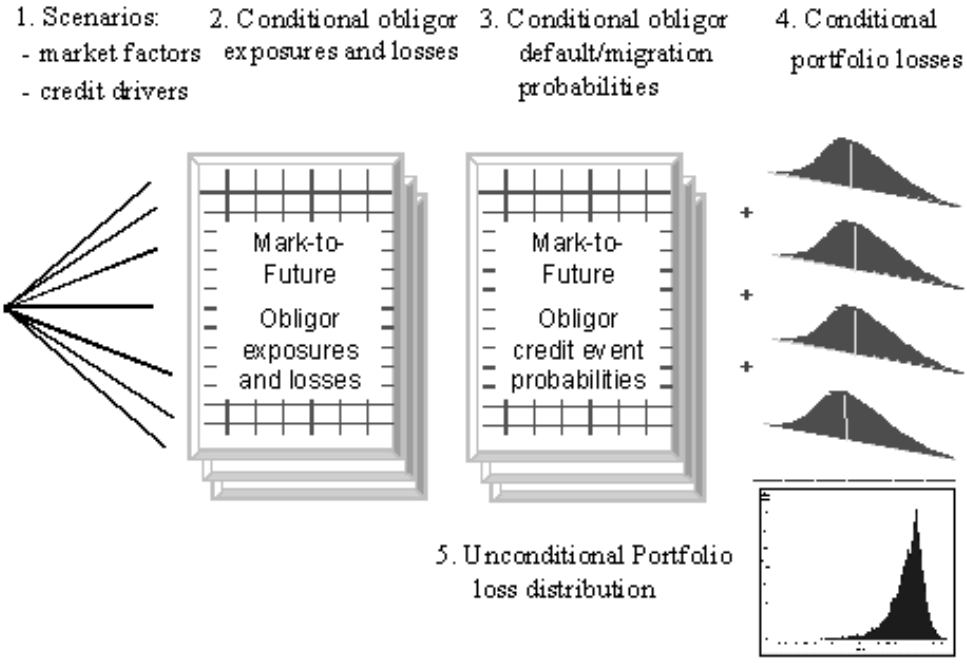

Figure 7: Outputs of each step in the MtF framework

Step 5: Aggregation of losses in all scenarios. Finally, the *unconditional* distribution of portfolio credit losses is obtained by averaging the *conditional* loss distributions over all possible scenarios.

Figure 7 presents a schematic describing the outputs of each step of the MtF credit risk framework.

The MtF architecture is key to obtaining a computationally efficient methodology that is also consistent with the overall risk management strategy of the institution. First, the portfolio credit risk solution can be seen as a secondary post-processing step applied to the counterparty exposures that are obtained from the MtF Cube as discussed in Step 2. This can be the same post-processed MtF Cube that is used to manage counterparty credit risk limits. Second, we can exploit the powerful property of conditional credit independence, as discussed in Step 4, to minimize the number of scenarios for which expensive portfolio valuations are calculated. Thus, advanced Monte Carlo or analytical techniques can be applied that take advantage of the problem structure.

In summary, the Mark-to-Future framework provides an accurate, computationally efficient, estimation of counterparty exposures and portfolio credit risk, which integrates the various sources of credit risk, as well as market risk. This integration is achieved through the scenarios that define explicitly the joint evolution of market risk factors and credit drivers.

From risk measurement to risk management

In addition to monitoring risk, an effective risk management framework must help the firm identify the sources of its exposures, understand the effects of market or portfolio changes on its risk profile, and obtain optimal risk versus return trade-offs. A comprehensive enterprise credit risk management tool kit allows the manager to:

- represent complex portfolios simply
- aggregate credit exposures across the trading and banking books, as well as across commercial and retail customers
- decompose credit risk by product and asset type and/or risk factor or credit driver
- explain the effect of new trades or credit derivative hedges on portfolio risk and value
- understand the impact of positions in non-linear credit instruments and of non-normal risk factor distributions on portfolio credit risks
- generate potential hedges and optimize a portfolio's risk/reward trade-offs.

The most widely used portfolio management tools are based on applications of MPT, originally developed by Markowitz and Sharpe. In spite of their onerous assumptions, such as normality of distributions, the insights provided by these tools form a solid conceptual basis for a risk management tool kit. However, the tools, as originally developed, cannot be effectively applied in most credit risk applications since credit loss distributions are far from normal with high skewness and long fat tails.

The main concepts of MPT can be extended in the Mark-to-Future framework to create a simulation-based risk management tool kit. In particular, MtF risk management tools have proven very useful for credit risk.

Simulation-based tools can be based on risk measures other than variance, such as Credit-VaR, expected shortfall and regret. They provide additional insights when the portfolio contains non-linearities, when the market distributions are not normal or when there are multiple horizons. Furthermore, they also explicitly model discrete markets, which are often observed in practice, where

trading may be costly and liquidity limited. Finally, simulation tools also naturally accommodate transaction costs, liquidity and other specified user constraints, as well as investor preferences.

Summary

This introduction motivates the development of a framework encompassing the integration of the many aspects of credit risk and reward across the enterprise. We outline the major business benefits and describe the necessary components of such a framework.

Four fundamental modelling requirements are emphasized:

- the simultaneous use of various credit risk models, recognizing obligor diversity and the need to integrate credit risk across the institution
- the accurate modelling of individual credit risky instruments, appreciating the diversity and ingenuity of credit markets
- the integration of market and credit risk, acknowledging that the current approach to managing in silos in unnatural and inefficient
- the construction of effective computational tools to not only measure risk, but also to manage and optimize risk and reward, recognizing that standard variance-based tools are generally not appropriate for credit risk applications.

The Mark-to-Future framework constitutes an efficient second-generation enterprise credit risk solution that satisfies these key objectives.

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Enterprise Risk Managementâ€”Integrating with Strategy and Performance (2017). In keeping with its overall mission, the COSO Board commissioned and published in 2004 the Enterprise Risk Managementâ€”Integrated Framework.Â This update to the 2004 publication addresses the evolution of enterprise risk management and the need for organizations to improve their approach to managing risk to meet the demands of an evolving business environment. The updated document, titled Enterprise Risk Managementâ€”Integrating with Strategy and Performance, highlights the importance of considering risk in both the strategy-setting process and in driving performance. For these reasons, market and credit risk, which are usually quite similar across the enterprise, will typically benefit from a centralized approach. Such an approach increases the efficiency and effectiveness of risk management because it allows for the sharing and refinement of good practices throughout the organization. To select the right approach, corporates first need to identify the risks inherent in their business model and then decide on the trade-offs between centralization and decentralization of their setup for each risk type. They might consider questions such as the following: Wh