CHAPTER 9

Measuring Risk

After reading this chapter you will be able to

- Differentiate between measures of exposure and measures of risk
- Consider the strengths and weaknesses of risk measurement methodologies
- Identify alternative strategies for estimating risks

Risk is the business of probabilities, and risk measurement is one component of risk management. Risk management involves identifying and measuring risk, followed by decisions about how best to manage it. Attempts to measure risk involve estimating the probability of an adverse event occurring and its potential impact. Volatility estimates are typically calculated using variance or standard deviation around the mean.

Measures of Exposure

To reduce risk, it is necessary to manage exposure. Measures of risk and exposure are one component of risk management and start with the following central questions:

- What is the exposure?

- How sensitive is the exposure?
- How much can I lose?

Market risk is the risk of an adverse movement in the price or value of a commodity, currency, or asset. Market risk measurement has primarily been developed in the financial institution sector, but methods have increasingly been adopted by other organizations. Quantifying risk is a complex topic, and this chapter will highlight some key points.

There are two views of risk management. The first is from the day-to-day or tactical standpoint. The second is a high-level or strategic view. In order to manage risk, it is necessary to have the capability to monitor risk from both standpoints in order to assess potential loss to the organization.

How Much Can I Lose?

There are several ways to estimate potential loss. The concept of probability is the central tenet of risk, and the business of risk measurement involves estimating the likely variability of returns. The term *risk measurement* is a bit of a misnomer. Risk measurement is an attempt to answer the question, "How much can I lose?" with reasonable certainty.

Quantitative techniques and rigorous processes can overshadow more mundane sources of significant risk and the need for common sense. Although attention must be paid to internal sources of risk, such as operational controls, other risks arise from external events and may be beyond the control of organizations that seek to manage them.

Risk management requires both quantitative and qualitative analysis. Unfortunately, risk management cannot be reduced to a simple checklist, process, or a single number. Trying to do so can create a mechanistic approach to risk management when one of imagination is needed.

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Process of Estimating Risk

The estimation of risk is a two-part process. The first part of the process is estimating the likely gain, or—more importantly in risk management—the likely loss, from changes in market rates or prices. To calculate potential loss, it is necessary to estimate the sensitivity of the instrument or exposure to market changes. Measures such as duration (for interest rates) are useful to estimate sensitivity to market changes.

The second part of the process involves estimating the probability of the aforementioned market changes. Given a potential change in market rates and the size of the underlying position, plus the probability of the change in market rates occurring, the potential loss (or gain) can be estimated. Alter any of the constituents of the assessment, and a different potential loss may result.

Gap Analysis

Gap or mismatch analysis measures the sensitivity of an exposure, asset, or portfolio to market rate or price changes by considering the mismatch between assets and liabilities. When there is a mismatch between assets and liabilities, or cash inflows and cash outflows, there is exposure and an opportunity for loss.

Gap analysis is traditionally undertaken by financial institutions managing the balance of assets to liabilities. A financial institution that wants to minimize the gap between its assets (loans and mortgages made to customers) and liabilities (deposits and accounts of customers) will group the financial assets and liabilities into maturity *buckets* or pools

based on their frequency of repricing or rate resetting. Maturity pools that have significantly more assets than liabilities (or vice versa) are sources of exposure.

Gap analysis can also be used to determine currency exposure arising from foreign currency cash flows. For example, if an organization has more euro inflows than outflows in a given period, but the mismatch reverses the following period, then the euro cash flows offset one another with only a timing difference. If over the course of a longer period, such as a fiscal cycle, there are more euros coming in than going out, the difference provides exposure to a falling euro.

Leverage and Direction

The use of leverage increases the potential for loss. Therefore, the impact of any leverage or gearing strategy is important to consider when calculating the amount that an organization could potentially lose. The calculation of potential loss without considering the impact of leverage underestimates potential losses.

Direction is the nature of an exposure or trading position, either long or short. A long position will obviously benefit from a rise in prices, while a short position benefits from a price decline. Both leverage and direction are factors in the potential size of a loss given an adverse market move.

Instrument Sensitivity

Measures of instrument sensitivity can be a useful way to measure potential for risk. Duration provides an estimate of the sensitivity of fixed income securities' prices to small changes in interest rates. Duration is also used for assessing gaps between assets and liabilities, since a timing mismatch is a source of interest rate risk. Duration has some limitations, particularly that it works better for small changes in

rates. Convexity, which measures the rate of change of duration, can be used to further refine the sensitivity of a fixed income security or exposure to interest rate changes.

Option delta is another measure of sensitivity. The option delta measures the sensitivity of the option's value given a change in the price of the underlying. Options that have little likelihood of exercise because their strike prices are far out-of-the-money have little sensitivity to changes in the price of the underlying asset. These options will therefore have a small delta. Options that have a greater likelihood of exercise will have a higher delta. The delta itself is subject to change, and is measured using gamma, which is the rate of change of delta.

Scenario Analysis

Scenario analysis (what-if analysis) offers a useful way to assess potential loss by analyzing the value of an instrument or portfolio under different, arbitrarily determined scenarios. Correlations are dynamic, not static, and therefore different correlation assumptions are used in different scenarios. In scenario analysis, it is necessary to make some assumptions about correlation, but a range of assumptions should be used in the different scenarios. In a crisis scenario, markets may become highly correlated with one another, increasing potential for loss.

Scenario analysis is straightforward and involves using a set of predetermined changes in market prices or rates (scenarios) to test the performance of the current portfolio or exposure. Most financial managers already perform ad-hoc scenario analysis calculations when determining potential outcomes of various decisions, markets, or transactions.

Scenarios may be one-factor scenarios, for example, assessing the results of a change in interest rates, or they may be multifactor, permitting a range of interest rate scenarios combined with a change in foreign exchange rates and a change in revenues. Specialized software permits

several different scenarios to be run simultaneously, with the results providing information about the potential for loss (or gain) under different scenarios, although simple scenarios can be captured in more basic software.

Modern scenario analysis generally assumes some asset correlation into future market movements, which is adequate when the scenarios are those that might be anticipated in a relatively normal market. Indeed, hedging itself is an attempt to protect the business activities of an organization from market risk.

Scenario analysis can be used to determine how assets will perform in relation to one another under relatively normal market conditions. Most traders use scenario analysis to assess strategic and tactical exposure. Scenario analysis is a useful methodology that can be used by all financial managers.

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Stress Situations

Scenario analysis is useful under ordinary circumstances involving routine market changes. However, in crisis situations financial markets may behave differently than they would be expected to. In severe market conditions, there is a danger that correlational relationships may break down. For example, markets that are expected to have low correlation may become highly correlated, at least in the short term.

In extreme situations or in markets where liquidity is marginal to begin with, liquidity may dry up completely for a short time. Without knowing how these relationships may change under duress, scenario analysis may not provide a complete picture of the portfolio's risk.

Scenario analysis is a useful adjunct to value-at-risk for risk measurement. Scenario analysis allows a risk manager to determine how a portfolio would behave under a predetermined set of scenarios. For example, using a set of arbitrary market scenarios to test the performance of a bond portfolio, a risk manager may determine the impact of a 50-basis-point parallel shift (up or down) in the yield curve. Scenario analysis is intuitively appealing because it answers the *what-if* part of the risk measurement question.

Although scenario analysis is intuitively appealing, it has limitations. For example, while a scenario of a 50-basis-point increase in interest rates might be useful, in the real world, yield curves do not shift in parallel. In real life, yield curves steepen and flatten in unpredictable ways across the maturity spectrum, and therefore not all models may fully capture such moves. As a result, a portfolio's changes should be evaluated under different yield curve scenarios, such as the following:

- Parallel shift with rising interest rates
- Parallel shift with declining interest rates
- Steepening of the yield curve, assuming a normal yield curve (longer rates rise more than shorter rates)
- Flattening of the yield curve, assuming a normal yield curve (longer rates rise less than shorter rates)

From a management standpoint, scenario analysis may facilitate management discussion and quantification of acceptable risk levels. A formalized discussion of risk is usually beneficial from a risk management perspective.

Stress Testing

Stress testing is similar to scenario analysis but is designed to assess performance under less frequent, but more significant, market moves. Stress

testing permits the risk manager to determine how a series of exposures would perform under additional conditions. A stress test may involve changing one or more variables or using major historical price changes to assess the potential impact to a financial instrument or portfolio.

Large moves often take market participants by surprise, and markets may move farther and faster than would otherwise be expected. These large moves may be combined with a breakdown in the typical correlational relationships that are present during normal market conditions.

Stress testing an organization's exposure can be very useful. In the event that the stress test shows unacceptable results in the form of unmanageable potential losses, strategies can be formulated to deal with the exposures and potential risks.

Financial Crises

Although financial crises occur with regularity, they are unfortunately not predictable. As a result, organizations should consider the ramifications of extraordinary market events, to the extent possible, in their risk management planning. This means ensuring an adequate financial risk management framework is in place, understanding current exposures, and avoiding overreliance on probability-based measures of risk.

Financial crises may be localized or global. Their attributes are similar:

- They occur relatively frequently.
- They are not predictable.
- Ordinary relationships, such as correlations between markets and instruments, may break down entirely.
- Proper preparation is required, including a risk management policy and an action plan.
- Systemic risk becomes the major concern to central banks and regulators.

The pressures leading to a crisis may be visible for some time prior to the triggering event. In financial crisis situations, ordinary relationships between markets may break down, exacerbating the effects of the crisis. It may be difficult to obtain market prices or information, and it may be costly to initiate or close out transactions. Liquidity and lines of credit often become quite scarce, and volatilities and spreads widen dramatically.

Some experts believe that financial institution consolidation may increase the risk of financial crisis. As consolidation reduces the number of market participants, it increases the likelihood that portfolios or positions of remaining large participants will be similar. Fewer differentiated participants may result in less portfolio and position diversity and greater risk of a crisis.

Value-at-Risk

The most commonly used measure of market risk is value-at-risk. Value-at-risk is a systematic methodology to quantify potential financial loss based on statistical estimates of probability. An estimate of the

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Notable Quote

"The key to truly effective risk management lies in the behavior of markets during times of crisis, when investment value is most at risk. Observing markets under stress teaches important lessons about the role and dynamics of markets and the implications for risk management."

Source: Richard M. Bookstaber, "A Framework for Understanding Market Crisis," *Risk Management, Principles, and Practices*, AIMR Conference Proceeding, no. 3, 1999. Copyright 1999, CFA Institute.

probability of a loss being greater than (or less than) a particular dollar amount as a result of market fluctuations, value-at-risk is commonly used to measure risk in a portfolio of assets or exposures.

Value-at-risk attempts to answer the question, "How much money might I lose?" based on probabilities and within parameters set by the risk manager. Value-at-risk calculations are based on one of several methods.

Value-at-risk creates a distribution of potential outcomes at a specified confidence interval. The largest loss outcome using the confidence level as the cut-off is the amount reported as value-at risk. Confidence intervals are typically 95, 97.5, or 99 percent. For example, at a 95 percent confidence interval, there is the probability of a loss being greater than $10,000,000 on 5 days out of 100 days.

Though the idea of a single number to quantify risk is inherently attractive, there are limitations in its use. Most important, it is possible to lose more than the value-at-risk amount. Value-at-risk is only one risk measurement tool, and it should be used in conjunction with a range of other risk measurement tools. Scenario analysis is one useful adjunct to value-at-risk.

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Notable Quote

"No amount of observations of white swans can allow the inference that all swans are white, but the observation of a single black swan is sufficient to refute that conclusion."

Source: Dave Hume, "Treatise on Human Nature." Quoted by Nassim Nicholas Taleb, *Fooled By Randomness—The Hidden Role of Chance in the Markets and in Life* (New York: Texere LLC, 2001), p. 100.

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Risk Measurement Model Challenges

There are risks involved with the reliance on risk measurement models. Issues to consider include:

- Data accuracy and availability issues
- Extreme price events that are infrequent but need analysis
- Ability to reflect optionality, including embedded options
- Overreliance on quantitative without understanding qualitative risk issues

Value-at-risk provides an estimate of the riskiness of a portfolio. In estimating potential for losses, value-at-risk provides information about portfolio weaknesses and exposures that can be subsequently addressed by the risk management group.

Although value-at-risk is a useful measure because of its ability to distill a great deal of information into a single number, there are strengths and weaknesses associated with it. Clearly, one of the key advantages of value-at-risk is its ability to focus both nonfinancial and financial managers on the issue of measuring risk. Despite its shortcomings, it may encourage a more systematic and multidimensional approach to financial risk.

Methods to Calculate Value-at-Risk

There are several ways to calculate value-at-risk. The methods vary in their need for market data, the computing power required, and the ability

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A Short History of Value-at-Risk

The widespread use of value-at-risk for risk management purposes is relatively new. The Group of 30's seminal 1993 *Practices and Principles* report recommended measuring market risk using value-at-risk with a standard time horizon and confidence interval (recommendations are found in Chapter 7). A survey that same year found only 5 percent of firms disclosed value-at-risk estimates to shareholders. Four short years later, the proportion had increased to 81 percent. The market was onto something.

Financial institutions had been working with value-at-risk variations for some time. However, J.P. Morgan's development of RiskMetrics[a] methodology for calculating value-at-risk was a major milestone in the evolution of risk measurement. Its introduction in 1994 provided many firms with their first exposure to value-at-risk. Originally known as the "4:15 report" because of the time it was delivered each afternoon, RiskMetrics was developed to give J.P. Morgan's new chief executive officer, Sir Dennis Weatherstone, a clear measure and view of the risks being taken by the firm's various activities.

The methodology, which had been developed internally for the firm's own market risk measurement, enabled virtually any firm to test-drive value-at-risk using the parametric approach. In doing so, it promoted a new approach to market risk transparency and provided a risk measurement benchmark. As a result, it was beneficial to both clients and the broader market. Value-at-risk has gained tremendous support from the

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international financial community and regulators, and progress in the refinement of methodologies and processes continues today.

a. RiskMetrics® is a registered trademark of RiskMetrics Group.

to model different types of instruments. Value-at-risk calculations are typically obtained using one of the following methods:

- Using historical data
- Using stochastic simulation, random or Monte Carlo scenario generation. Monte Carlo simulation is based on randomly generated market moves. Volatilities and correlations are calculated directly from underlying time-series data, assuming a normal distribution.
- Value-at-risk using the variance/covariance (parametric) approach. Volatilities and correlations are calculated directly from the underlying time series, assuming a normal distribution.

Assumptions and Limitations

Value-at-risk calculations introduce some important assumptions and limitations. These assumptions and limitations should be understood in the context of their implications for measuring and managing risk.

Financial markets, and in particular, the returns of many assets, are not normally distributed. Rather, there is a tendency to have larger outlying results (known as *fat tails*) than would be expected with a normal distribution, and peaks around the mean. Large losses are more likely, and typically more important to the risk manager, than gains of the same magnitude.

In addition, most value-at-risk models make the assumption that returns each period—each day, for example—are independent of one another, which market history shows is not always the case. The market's behavior yesterday has much more impact on today's prices than events last year.

Depending on the methodology used, the calculation of value-at-risk can be quite demanding. For example, the computing power required to analyze a portfolio of cash flows for thousands of instruments for a large financial institution or trading house is not insignificant.

Although a single risk number is intuitively attractive, its simplicity is also a limitation. Value-at-risk does not consider all risk factors, nor does it perform well as a risk measure for nontraded exposures. It also does not consider how market correlations might change or disintegrate under extreme conditions in a financial crisis. As a result, risk measures are at best an estimate of potential loss.

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Senior Management

Senior management and the board of directors must be cognizant of value-at-risk's meaning when presented regularly with reports that appear to quantify maximum loss based on risk measures such as value-at-risk. There may be a weak understanding of the concept of value-at-risk. In particular, it may be poorly understood that there is a small probability of losses much greater than models predict. In addition, management may not fully comprehend the importance of non-market risks, such as operational failures, that can also result in significant losses.

Risk measurement may convey a false sense of security among management that financial risks have been measured and that they are therefore being managed appropriately. Risk measurement is only one component of risk management, and many organizations have been good at measuring risk but poor at managing it. Markets are always capable of unexpected results. As a result, best efforts at measuring risk will never fully capture potential future outcomes, even if estimates are good most of the time. The occasional poor estimate of risk may be the proverbial iceberg.

Value-at-Risk Using Historical Simulation

One way to calculate value-at-risk is to use past returns to simulate future returns as a guide to estimating potential loss. Under historical simulation value-at-risk, the portfolio is repriced for a predetermined number of historical periods (e.g., 200 days).

The resultant returns, ranked by magnitude from best to worst, provide a snapshot of the portfolio's value under historical market data with the worst results commonly at the 95 percent level (excluding the worst 5 percent of returns) or the 99 percent level (excluding the worst 1 percent of returns). The worst returns are the ones that most interest the risk manager. The result provides useful information about the risks associated with the current portfolio based on historical market movements.

There are advantages to the simplicity of historical simulation for the calculation of value-at-risk. The methodology is relatively intuitive and easy to understand. It does not make assumptions about the future shape of distributions of returns, volatility, or the correlations of returns between assets other than those that are implied by past returns. As a result, the historical simulation method is suitable for portfolios with nonlinear instruments, such as options.

However, historical data available may not be representative of the market over the long term, and markets can change over time. In addition, the historical data may not contain an appropriate market event, or it may be subject to an ongoing directional price trend. The historical period may not have exhibited any unusually large movements or the kinds of moves that a financial manager might wish to observe in the portfolio.

Value-at-Risk Using Monte Carlo Simulation

Monte Carlo simulation involves computing value-at-risk using tools that automatically generate large numbers of random price or rate changes. These price changes are applied to the portfolio of assets or exposures and the results are measured. The worst results of the resulting distribution are considered the value-at-risk amount, using a specified confidence level.

One advantage of Monte Carlo simulation is that it allows a financial manager to use the results of hundreds or thousands of scenarios to calculate value-at-risk. The resultant frequency distribution can be used to determine value-at-risk with the desired confidence interval.

The risk manager can specify distributions and parameters, or use historical or forecast volatility data, depending on the requirements. Although it is an extremely useful tool, the analysis of large or complex portfolios requires adequate technology to be effective, as computational complexity may be high depending on the portfolio's constituents.

To better understand computational requirements, consider a portfolio of long-term interest rate swaps. Swap values depend on the present value of the cash flows associated with them. Each swap may have dozens of future cash flows. Repricing thousands of swaps in a value-at-risk simulation with a thousand or more scenarios is not an insignificant task.

Monte Carlo simulations are typically accomplished using specialized software. Innovations in technology and simulation have made the

calculations using Monte Carlo simulation for large, complex portfolios more accessible and cost effective.

Value-at-Risk Using the Parametric Approach

The parametric approach to calculating value-at-risk is also known as the variance/covariance method, the correlation method, or the analytical method. Of the parametric models available, the best known is probably RiskMetrics.

The parametric approach to value-at-risk has origins in modern portfolio theory, where the risk of a portfolio of assets is assumed to be a function of the risk or variability of each instrument in the portfolio and the correlations between instruments in the portfolio.

The parametric value-at-risk methodology is often combined with another methodology for analyzing the behavior of nonlinear instruments and exposures. The traditional parametric approach is not effective for all types of assets or instruments such as options.

Credit Risk Measurement

Credit risk is the probability of loss as a result of the failure or unwillingness of a counterparty or borrower to fulfill a financial obligation. Exposure to credit risk increases with the market value of outstanding financial instruments with other counterparties, all else being equal.

Counterparty Ratings

Financial institutions have significant exposure to credit risk due to the nature of their various activities and the number of transactions involved. Due to their exposure, these financial institutions tend to be at the forefront of credit risk measurement and management.

The traditional management of credit risk entailed monitoring many aspects of a borrower's affairs. One of the most fundamental

aspects of credit risk management today is the careful selection of an appropriate counterparty. In trading, the selection of counterparties is very important. Counterparties with financial stability, acceptable ratings, familiarity, political stability, satisfactory geographical location, and appropriate legal form of organization are chosen.

The global financial community extensively uses ratings provided by major rating agencies. These companies rate specific securities offerings, typically debt, and are used by institutional investors such as mutual and hedge fund managers, lenders, and individual investors. Ratings are used to assess creditworthiness and thus the likelihood of a default by the issuer. They are not a substitute for counterparty risk management.

Organizations monitoring credit risk may require that trading counterparties, issuers, or potential creditors have a minimum acceptable rating from at least one of the major ratings agencies.

Notional Exposure

Notional, contractual, or nominal amounts outstanding are sometimes cited as amounts at risk. Depending on the source of the exposure, however, such an assessment may be too simplistic. In traditional creditor roles, such as lending, trade receivables, or similar, the full notional amount is at risk because the borrower or debtor may choose not to pay amounts owed. The notional amount of the debt then becomes the potential loss, less any residual collections that can be made.

With many derivatives transactions, such as interest rate swap where net payments are made between counterparties, less than the notional amount may be at risk. For other derivatives, such as currency swaps, payments may be more significant, and the full amount may be at risk, especially during settlement.

Notional amounts are important in the discussion of settlement risk. When both counterparties to a trade settle in full by making pay-

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NRSRO Rating Agencies

There are credit rating agencies in major countries around the world. Agencies whose credit ratings are used under the U.S. Securities and Exchange Commission (SEC) regulations are known as nationally recognized statistical rating organizations (NRSROs):

- Dominion Bond Rating Service Limited (DBRS), www.dbrs.com
- Fitch, Inc., www.fitchratings.com
- Moody's Investors Service, Inc., www.moodys.com
- Standard & Poor's Ratings Services (S&P), www.standardandpoors.com

Debt offerings of many governments and corporations are rated by one or more of these rating agencies, which may change from time to time. Issuers pay to be rated by agencies. Although the use of ratings published by independent rating agencies provides some guidance, it is not infallible, and there have been unexpected and spectacular failures of rated organizations. More information can be obtained from the SEC.

ments to one another, the failure of one counterparty to pay could result in the loss of the entire notional amount to the other counterparty. Settlement risk gives rise to the potential for a loss of the notional amount, and therefore it should be managed carefully.

Aggregate Exposure

Given the importance of credit risk in both derivatives and nonderivatives transactions, it is important to be able to determine total exposure

to a counterparty at any point in time and compare these aggregates to established in-house counterparty limits. This is a key measure to monitor an organization's exposure.

Organizations should aggregate credit exposure to individual counterparties. Aggregate totals can be netted in those situations where there is a legally enforceable netting agreement in place between the counterparties and for the transactions.

Replacement Cost

Both current and potential exposures that arise from derivatives contracts can be assessed. Current exposure, or replacement cost, can be determined by reviewing the market value of outstanding contracts. The marked-to-market or current value can be considered a measure of replacement cost and therefore a measure of risk. If the derivatives counterparty defaulted on its obligations, replacement cost measures the cost to replicate the position at current market prices, presuming no settlement issues. Potential exposure can be calculated using probability analysis.

Credit Risk Measures

Credit risk measures are based on probability estimates of loss resulting from a default. They depend on the probability of the counterparty defaulting, the organization's exposure to the defaulting counterparty at the time of default, and any amounts that can be recovered after default. These individual determinants of credit risk can be summarized as:

- Probability of counterparty default, which is an assessment of the likelihood of the counterparty defaulting
- Exposure at counterparty default, which takes into account an organization's exposure to a defaulting counterparty at the time of default

- Loss given counterparty default, which considers recovery of amounts that reduces the loss otherwise resulting from a default

Default risk, or the probability that a default occurs or does not occur, is modeled by many organizations, including rating agencies. Although a default can be modeled as an independent event, losses from defaults often depend on both the probability of an individual default and the correlation between defaults of different counterparties or obligations.

Credit value-at-risk provides a distribution of potential credit losses over a specified time horizon and examines the credit value-at-risk at a particular confidence interval. The risk manager can then review those exposures that contribute significantly to an organization's credit risk and take remedial action, if necessary.

Credit derivatives markets reflect the assessment of risk by market participants. Prices based on actual transactions between relatively sophisticated participants may provide insight into the market's assessment of the riskiness of an organization. Therefore, prices such as those of credit default swaps may be a useful adjunct to other credit risk measures.

Future of Credit Risk Measurement

Major steps are being taken in the development of various quantitative methodologies to model and measure credit risk. In part, the revised Basel II framework for capital requirements has led to the implementation of highly sophisticated credit risk management capabilities on a global scale and the improvement of existing methodologies. These credit risk measurement and management capabilities will inevitably filter down from large financial institutions to smaller organizations. Basel II is discussed in more detail in Chapter 10.

Operational Risk Measurement

Operational risk, which is discussed in more detail in Chapter 7, results from an organization's exposure to people, processes, and systems. Operational risk management exists to reduce the possibility of fraud or error resulting in loss to the organization. Many of the large bank trading losses that have been widely reported in the media have been due to operational failures.

Some methods that have been used to measure or indicate potential for operational risk in financial institutions and other organizations include:

- Number of deviations from policy or stated procedures
- Comments and notes from internal or external audits
- Volume of derivatives trades (gross, not netted)
- Levels of staff turnover
- Volatility of earnings
- Unusual complaints from customers or vendors

Increasingly, operational risk databases are used to model operational risk for probability of occurrence and aid in risk reduction. The operational risk database is used to identify and assess potential risks and track their occurrence. Resulting data can be used as an input to model operational risk occurrence probabilities and potential losses. For operational risk events, the probability of an individual occurrence may be small but have potential for a significant loss.

In related audit and fraud prevention areas, probability assessments are also used. In addition, the insurance industry quantifies particular operational risks in order to price various types of insurance coverage. However, this expertise is relatively specialized and usually beyond the scope of general financial risk management.

Summary

- The concept of probability is the central tenet of risk, and the business of risk measurement involves estimating the probability of loss.
- Scenario analysis involves using a set of predetermined changes in market prices or scenarios to test the performance of the current portfolio or exposure.
- The most commonly used measure of market risk is value-at-risk, a systematic methodology based on statistical estimates.
- As the costs of computation decline and user sophistication increases, the number and variety of risk management tools has increased substantially. More rigorous measurements of risk will likely become commonplace.