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The Art and Science of Risk Management

1.1 THE "BRAVE NEW WORLD" OF RISK MANAGEMENT

As any practitioner can attest, interest in risk management is highly correlated with large shocks to the financial system, their attendant dislocations, and the subsequent headlines and witch hunts. In fact, nothing focuses the mind better than surviving a brush with financial ruin or witnessing the demise of an institution similar to your own. Conversely, long periods of financial stability tend to make the life of a risk manager a lonely one, making him seek refuge in extracurricular activities, like starting a new hobby or writing a book. The evolution of the ideas presented in this work is a vivid illustration of this phenomenon. We started thinking about writing a book in 1996 when the market environment was characterized by optimism and confidence, high liquidity, tightening of credit spreads, and the "exuberant" rally in the stock markets of developed and emerging countries. Given the benign nature of basis risk factors at that time, interest rates accounted for the overwhelming majority of risk associated with investing in fixed income securities.

The Asia meltdown of October 1997 changed this tranquility, heightening attention to risk management. Besides interest rates, a host of other risk factors became significant, including emerging market credit spreads, liquidity, and exchange rates. The events of that memorable month highlighted the impact of globalization on the capital markets' behavior. One year later, the credit and liquidity crisis of fall 1998 and the unprecedented turbulence in the financial markets became an even more persuasive illustration of the changed nature of financial risks. The financial near-demise of many well-respected practitioners and academics (e.g., Long-Term Capital Management) forced all market participants to take a deep and more focused look at their practices, procedures, and assumptions, hence revealing new intellectual and technological challenges facing risk management.

However, by early spring 1999, the Dow Jones Industrial Average (DJIA) was back at historical highs, interest rates reverted to more "normal" levels, and credit spreads tightened dramatically across most all spread-sensitive asset classes (Table 1.1). With the U.S. economy strong, stock markets rallied, emerging and high yield markets rebounded, liquidity improved, and the fears and concerns of fall 1998 seemed to be left behind. Some investors began wondering what the fuss was all about, fearing a different kind of risk this time around – the risk of *not having enough exposure* during a bull market. Nevertheless, the financial crises did teach market participants a number of valuable lessons. They highlighted the ever-changing nature of financial markets and taught investors to treat catastrophes not as *highly unlikely* but rather as *infrequent but on average regularly occurring* events. Taken in that light, the challenges facing modern risk management appear greater than ever before, and a deeper understanding of risk and the mechanisms by which financial markets are implicitly linked is vital.

The term *risk management* has been increasingly appropriated to incorporate the full range of potential problems with financial assets, such as administration, compliance, technology, and fraud control. While certainly acknowledging the extreme importance of these business risks, this book purposely limits the scope of risk management to

TABLE 1.1 DJIA, 10-year U.S. Treasury Yields, and 10-year Swap Spread (as of 10/5/98, 4/29/99, and 12/31/99)

	10/5/1998	**4/29/1999**	**12/31/1999**
DJIA	7,726	10,878	11,192
10-year OTR TSY (%)	4.18%	5.23%	6.11%
10-year Par TSY (%)	4.31%	5.40%	6.28%
10-year Swap Spread (basis points)	94	72	83

market risk management, focusing on the problems unique to applied financial modeling and its applications to portfolio management, trading, hedging, and other areas of financial decision making.

To illustrate the evolution of risk management as a discipline, let us compare and contrast the financial disasters that made the headlines in the 1980s and early 1990s versus the more recent ones. Consider some of the earlier landmark failures, all of which were characterized by missing knowledge or systems, a lack of models and analytics, oversight, or non-recognition of risk:

- S&L bailout – limited understanding of yield curve risks
- Orange County – leveraged risks without adequate monitoring and measurement
- Askin Capital Management – missing analytics
- Kidder Peabody – limited ability to manage risk of complex securities (e.g., Collateralized Mortgage Obligations: CMOs) through interest-rate cycles

More recent financial failures have been of a very different nature. They generally involved highly sophisticated financial entities who, despite their knowledge of their portfolio risk characteristics, were forced to simultaneously respond to unusually large and sudden market dislocations, including Russia's default, a widening of credit spreads, and a collapse in liquidity:

- Long-Term Capital Management (LTCM) – extremely complex leveraged positions stressed beyond equity capital[1]
- Laser Mortgage Management (LMM) – high leverage and large concentrations of risk combined with a loss of liquidity

Analysis of recent market catastrophes enables us to glimpse into the future of risk management. First and foremost, players today are much more analytical, knowledgeable, and conscious about quantitative analysis and risk management. Their increased sophistication is due to a variety of recent advances in technology as well as financial theory. On the technological front, tremendous improvements in computational capabilities and reduction in costs have allowed the pricing and analyzing of thousands of complex, path-dependent securities on a daily basis. Problems that were considered futuristic only a decade ago can now be solved. In addition, libraries of fixed income securities were reverse-engineered and made accessible to investors through software vendors such as Bloomberg, Bridge/EJV, Salomon Brothers' Yield Book, Trepp, and CMS Bond Edge. With basic "meat-and-potatoes" analytical capabilities in place, practitioners were able to move on to new and more exciting intellectual problems.

The fixed income investment universe has expanded dramatically over the last few years. As domestic markets were becoming increasingly efficient, investors began searching for excess return by expanding their holdings into more esoteric types of derivatives, illiquid securities, nondollar and real estate debt, emerging market bonds, and other asset classes. While creating (at least in theory) diversification benefits on the portfolio level, this presented investors with "unfamiliar combinations of risk,"[2] dramatically complicating the task of measuring and managing financial risk. To adapt to the new realities, financial modelers and risk managers were forced to raise their analytical systems to a whole new level. Therefore, the news of BARRA's discontinuation of its existing line of domestic fixed income risk management products after almost 20 years of interesting work in this field is not at all surprising.[3] The costs of developing and maintaining risk management systems are increasing at an astonishing rate and are expected to intensify in the future. In today's competitive environment, a successful investment process must rely on analytical, risk management, and technological infrastructures as never before. The tasks of understanding a wide range of fixed income products and efficiently managing hundreds of portfolios against numerous customized benchmarks in a risk controlled fashion demand greater resources. The increased sophistication of clients and their awareness of risk management techniques present additional challenges. Understanding a client's investment objective and having systems in place that track positions, trades, and historical performance is no longer sufficient. In addition to these basic capabilities, client's risk preferences and utility functions must be translated into the language of risk management; sources of active return over the benchmark must be understood; and a variety of interest rate, currency, and basis risks must be measured and explicitly managed. Finally, the emergence of the World Wide Web has enabled investors to have continuous access to their investment portfolios, fundamentally altering the nature of communication between asset managers and their clients and creating the highest levels of transparency.

In his anti-utopian novel *Brave New World,* Aldous Huxley portrays a society that chooses to sacrifice feelings, emotions, and "high art" for the sake of *stability.* In some sense, the discipline of risk management is an analogous construct in the financial markets. Ironically, the individual pursuit of stability through the practice of risk management may have made financial markets *more directly susceptible* to market risk. This paradox has arisen because as financial markets became more global, dynamic, and intertwined, "standard" risk management practices began to propagate. As a result, traditional concepts of financial diversification (holding portfolios of assets with uncorrelated systematic sources of risk) are becoming undermined by common risk management practices of progressively similar capital pools. The use of similar risk management techniques by an increasing proportion of the financial system (asset managers, hedge funds, mutual funds, banks, insurance companies, etc.) leads, in times of crisis, to similar reactions by market participants to financial catastrophes:

- *Similar goals.* In times of turmoil, investors try to reduce total risk per unit of capital and/or raise cash to cover margin calls.
- *Similar response.* First, they naturally attempt to sell illiquid positions. After discovering "no bid" (huge and unrealistic spread widening on thin trading) for illiquid securities, liquid positions have to be sold, regardless of which market they are in.[4] This phenomenon may create correlations among asset classes that are fundamentally uncorrelated.
- *Vicious circle of liquidity.* Lenders increase "haircuts" on illiquid leveraged positions, thus forcing additional liquidations, further depressing the value of illiquid positions, and, in turn, exacerbating margin calls. At the same time, dealers become reluctant to take long or short positions of any significant size and widen bid/ask spreads.
- *Model risk.* Reliance on similar quantitative models can create dangers of its own since the behavior of financial markets changes fundamentally in times of crisis.[5]

The following examples illustrate how market dynamics changes due to adoption of similar risk management practices.

1. *Portfolio insurance in 1987.* Everyone is familiar with the impact that the infamous risk management technique, *portfolio insurance,* had on the stock market in 1987. The fact that "portfolio insurance caused the crash remains disputable; that it exacerbated the market movement is a certainty."[6] Instead of buying options outright, portfolio insurance attempted to use dynamic option replication strategies to mitigate market risks. Similar to *stop-loss* policies, portfolio insurance generated further selling as a result of lower market prices, only aggravating the sell-off.

2. *Hedging mortgages in the 1992 rally.* In 1992, interest rates fell dramatically after years of relatively high rates. Despite the fact that Wall Street had spent millions of dollars developing interest rate and prepayment models, the mortgage market did not trade to the durations predicted by their state-of-the-art option-adjusted spread models.[7] As a consequence, most mortgage investors sooner or later realized that rather than assuming that every financial problem has an analytical solution, subjective estimates must be created, managed, and incorporated into financial models. In the subsequent 1994 rally, lessons learned two years earlier manifested themselves in the fear of ever-shortening mortgage durations. This led to aggressive buying of U.S. Treasury securities that further strengthened the rally and exacerbated the shortening of mortgages.
3. *Credit spreads in fall 1998.* Russia's default on its sovereign debt created losses for many large financial institutions, the complete scope of which was not fully understood. The heightened credit risk aversion caused a dramatic widening of credit spreads, putting pressure on highly leveraged institutions, LTCM being the most prominent. As rumors spread and losses increased, risk management units uniformly started paring back positions and cutting credit lines. These actions, in turn, exacerbated the crisis that could have posed a serious threat to the entire financial system if not for the extraordinary initiative by the Federal Reserve to stabilize LTCM.

Financial markets constitute a complex, dynamic self-learning system. As a rigorous quantitative discipline that attempts to model this system and forecast its behavior, risk management has attracted a lot of brilliant people with academic backgrounds in physics, mathematics, and other natural sciences. While usually providing great insights into the analytical aspects of financial phenomena, these "rocket scientists" may oversimplify financial modeling problems by mapping the unchanging nature of most physical systems onto the evolving and adapting behavior of the nearly efficient financial markets. Since the underlying "truths" of financial markets (as determined theoretically or empirically) regularly change as more market participants learn about them, very few problems in other fields of human knowledge can compete in complexity with financial modeling. While the laws of physics do not change when an important relationship is discovered, fundamental characteristics of financial markets *do* change as knowledge about them is assimilated into the practice of market participants. The stochastic behavior of systematic risk factors and even their cause-and-effect relationships “mutate” because of investors’ knowledge about them. Hence all risk management practices require frequent “reality checks” to verify that the forecasts of risk models are still consistent with actual market behavior. For instance, if a price movement is inconsistent with the predictions of a risk model, either the price is wrong,[8] the security has out- or underperformed the market, the model is broken, or the model’s structure has become outdated. If the premise is accepted that the market teaches one about risk rather than risk being derivable from theory, then a concept of “objective risk criteria,” bounced around longingly in the pension fund world, is fundamentally flawed. Because market risks continually change, the methodologies that measure them must evolve as well. By the time a risk becomes “objective,” its characteristics may have changed materially.

Advancements in technology have made desecuritization an important trend influencing risk management. Back in the early 1980s, the emergence of powerful centralized computing and database capabilities enabled the introduction of various types of structured products, including mortgage-backed securities, credit card receivables, and the like. By securitizing large pools of individual loans, a spectrum of liquid securities was created, reducing costs and seemingly eliminating the need for significant informational and technical expertise. Explicitly or implicitly, the law of large numbers was invoked to persuade investors that they were getting securities with “average” characteristics. In practice, however, the provided information was often purposely limited in an attempt to enhance the liquidity of subsequent issues of sometimes dissimilar pools of assets. Today, technology is starting to reverse this trend as investors are able to efficiently pierce securitization shells and monitor pools of assets on a disaggregated basis. Massive data sets can now be stored and transferred at reasonable costs, and data mining and visualization techniques make it possible to manipulate gigantic amounts of data and interactively investigate multidimensional relationships on a computer screen. For example, when forecasting short-term prepayment characteristics of servicing portfolios, financial institutions can employ increasingly sophisticated modeling techniques to capture the information contained in detailed borrower-specific data, including mortgage application files, prepayment histories, credit card and bank account information, and so forth. While previously infeasible due to computational constraints, use of extensive data sets has improved the forecasting power of empirical models by an order of magnitude. This type of analysis is indicative of the future because technologically sophisticated investors will be positioned to add additional value by analyzing the data underlying complex structured securities.

In a world of pervasive analytical capabilities, modern risk management will be faced with challenges specifically related to applied financial modeling. Thus, portfolio-level analytics needs to identify common risk characteristics among diverse types of assets and quantify aggregate exposures through common denominators. In addition to interest rate risk and yield curve risk, which are well understood and modeled, systematic behavior of basis risks and their relationships with interest rates, currencies, and other systematic risk factors must be carefully studied. Increasingly sophisticated statistical, econometric, and financial methods need to be developed to estimate "fat tails" and unstable empirical relationships, including incorporating catastrophic events into business-as-usual distributions. In the absence of such models, the need for incorporating subjective judgement into risk management becomes even greater. Thus, since practitioners are taking on a more cautious view of the ability of statistical models to measure catastrophic risk, application of market knowledge and intuition in developing approaches to stress testing is critical.

Risk management is becoming more prominent in the life of financial institutions. No longer perceived by traders and portfolio management as a controlling or "policing" function that simply limits the upside, it is turning into an invaluable quantitative resource for all stages of the investment process. The risk-taking culture and the risk management culture are merging together, as the financial markets keep reminding investors that while one cannot make money without taking risks, the long-term viability of institutions is put in jeopardy if risks are not managed properly and relentlessly.

Predicting how the Brave New World of risk management will evolve in the future is difficult. The only certainty is that the tasks of measuring and managing risk will become even more complex and demanding, both conceptually and computationally. Given the rapid changes in the financial markets and products, it is the ability to successfully deal with these challenges that will determine long-term success or failure.

1.2 MARKET RISK MANAGEMENT PROCESS

Market risk management can be thought of as consisting of the following distinct stages:

1. Identification of relevant systematic risk factors
2. Measurement of market exposures
3. Estimation of joint probability distributions
4. Computation of risk measures and explicit risk mitigation and management

Risk management starts with the task of identifying all relevant *systematic risk factors,* exogenous variables that cause fluctuations of market prices of securities and portfolios. Some risk factors are *directly observable* and *measurable* macroeconomic variables, such as Gross Domestic Product (GDP), mortgage origination rates, yields on U.S. Treasury and other liquid securities, foreign exchange rates, swap spreads, and so forth. Other risk factors cannot be directly empirically observed. Among others, they include *composite* variables (spot and par rates, principal components, option-adjusted spreads, etc.) that can typically be derived from a set of directly observable risk factors. To fully understand the price behavior of a security or portfolio, all applicable risk factors have to be identified. For complex multicurrency fixed income portfolios containing derivatives and esoteric spread products, the number of relevant risk factors can be hundreds or even thousands. The "observable and measurable" criterion is crucial. For practical purposes, identifying a risk factor that cannot be accurately measured is useless. For instance, the behavior of certain types of mortgage derivatives (e.g., mortgage servicing rights, esoteric CMOs, Commercial Interest-Only Mortgage Backed Securities [CMBS IOs] etc.) as well as certain emerging market debt would be better understood if these markets were more liquid and the corresponding time series of nominal or option-adjusted spreads were available. Unfortunately, due to the illiquidity and lack of transparency in these markets, it is difficult to have confidence in their historical time series of credit spreads. This example illustrates that in practice it is necessary to identify fundamental risk factors that can be reliably measured. They sometimes serve as proxies for more relevant but unobservable risk factors.

Once the set of applicable risk factors has been identified, the second stage of risk management involves measuring exposures of securities to each risk factor and aggregating these exposures across securities in a portfolio. This problem can be solved in two different ways. A security's exposure to each risk factor can be measured in isolation, with all others being fixed. In mathematical terms, this is equivalent to taking a partial derivative of a security's price with respect to the given risk factor. Measures such as option-adjusted durations, key rate durations, spread durations, and others presented in Chapter 2 serve as examples of partial derivatives. Methods that use various partial derivatives are popular because of their simplicity. One drawback of these methodologies lies in their historical implausibility, since rarely does a risk factor move in isolation, with all others unchanged. Also, accurately predicting price movements with partial derivatives (*local* measures of price sensitivity) may not be always possible when the changes in the underlying risk factors are large. Last, this setting makes capturing the intricacies of interaction among various risk factors difficult, both conceptually and computationally. Irrespective of the traditional criticism of measuring market exposure using partial derivatives, they constitute a very useful portfolio and risk management tool by presenting price sensitivities in a simple and intuitive fashion. As an alternative to employing partial durations to measure risk associated with isolated movements of each risk factor, price sensitivity of securities and portfolios to the *simultaneous* change in several risk factors can be investigated. Approaches of this type include option-adjusted durations that capture the interest rate directionality of basis risks as well as principal components durations.

Even after (1) all relevant risk factors have been identified and (2) the exposure of securities and portfolios to them has been measured, the ability to judge market risk is still incomplete without knowledge of the joint probability distributions of systematic risk factors. For instance, adding a new (nonvolatile) security to a portfolio may have a diversification effect if the returns on this security are (substantially) negatively correlated with returns on the original portfolio, but may actually have a risk-amplifying effect if the returns on this security are highly volatile or if their correlation with returns on the existing portfolio is positive or not sufficiently negative. On a similar note, identical market exposure to two different risk factors does not imply the same level of risk because price volatility is a function of both market exposure and the volatility of the underlying risk factor. Insights into the risks of complex portfolios without information about the volatility of relevant systematic risk factors and knowledge about their interaction are limited. The third and crucial step of market risk management therefore involves estimation of the probabilistic distribution of risk factors. For the sake of tractability, risk management models commonly assume that *instantaneous changes in risk factors follow a joint normal distribution.* Normal distributions are fully defined by the vector of *volatilities* (standard deviations) and the matrix of *correlations* of the corresponding random variables. Recent advances in applied statistics, including ARCH/GARCH approaches and dynamic time series modeling, have enabled construction of sophisticated statistical models of financial time series data. Risk management employs these methods in estimating historical volatilities and correlations of changes in systematic risk factors.

While econometric models may fit historical data well and provide insights and intuition behind the historical behavior of financial markets, they often fail to accurately forecast future movements and relationships, which is not surprising. On July 31, 1998, for instance, based on the three years of historical swap spread data, extrapolation using time series models would have predicted that swap spreads would likely be nonvolatile in August–October 1998. Due to their exclusive reliance on historical data, these models were unable to forecast unexpected *exogenous* events, such as Russia's default and the dramatic widening of credit spreads in fall 1998. The swap spread widening in August–September 1998 constituted anywhere between a 7 and a 10 standard deviation event, depending on the methodology used to estimate the historical volatility on July 31, 1998. Under the normal distribution assumption, a 7 standard deviation event corresponds to the less than a 1-in-700,000,000,000 chance. Clearly, the methodology used to draw conclusions about the statistical magnitude of swap spreads in this example is unrealistic: either the normality assumption is inadequate, the standard deviation is misestimated, or approaches of this kind are too primitive to adequately address catastrophic events and structural breaks in the system. Thus, the majority of statistical models currently in use, while fitting historical data well, may often fail to predict fundamental changes in the behavior of risk factors and are unable to account for paradigm shifts. These include the sudden emergence of some economic variables (e.g., leverage or credit spreads) as key forces driving financial markets after long periods of subdued behavior. Conversely, some of the previously influential risk factors may temporarily or permanently become unimportant. For instance, the employment cost index and other economic indicators that greatly influenced the market in 1993–1997 as predictors of interest rate movements became virtually unnoticeable in mid-1998 when global markets, rather than the state of U.S. economy, influenced the Federal Reserve's decisions. Models based on historical information alone are unable, by construction, to capture these types of phenomena. This argues for an increasing incorporation of subjective judgement into risk management models, making it imperative to develop risk management models flexible enough to allow for the addition of new risk factors and the deletion of those that are no longer applicable.

After (1) risk factors have been identified and measured, (2) exposure of securities and portfolios to these factors has been determined, and (3) models that estimate the joint distribution of risk factors have been built, the fourth and final step in the risk management process involves the actual computation of risk measures. The vast majority of methodologies described in this book are designed to measure the absolute risk of fixed income securities and portfolios as well as the relative risk of portfolios vis-à-vis their benchmarks. Thus, we start by estimating exposure of individual securities to a particular type of systematic risk or to market risk as a whole. Then we aggregate risk across the portfolio's holdings. This enables measurement of the risk of portfolios (or *assets*) as well as the risk of their benchmarks (or *liabilities*) since the latter can usually be represented as portfolios of fixed income securities as well.[9] The *gap* between assets and liabilities can be thought of as a portfolio consisting of two positions: a long position in assets and a short position in liabilities. The relative risk of a portfolio of assets vis-à-vis its benchmark can therefore be computed as the risk of the gap.

In addition to risk measurement, this stage of the market risk management process also involves understanding the advantages and disadvantages of alternative risk methodologies, working with decision makers on translating their risk/return preferences into the language of risk management, and identifying a wide range of practical applications for portfolio and risk management. The ultimate success of risk management is achieved when quantitative tools are used not only to measure, monitor, and explicitly mitigate risk, but when they become a valuable resource in a variety of day-to-day investment activities, including asset allocation, portfolio management, and trading.

1.3 THEORY, PRACTICE, AND COMPUTATION: CHALLENGES SPECIFIC TO FIXED INCOME MARKETS

Fixed income investment management is characterized by the relationship among theoretical models and concepts, their practical implementation, and the role of computational resources. Problems that are trivial to solve theoretically are often impossible to apply in practice due to a variety of reasons, including an absence of historical information, the ever-changing composition of portfolios and their evolution through time, a large number of macroeconomic risk factors influencing asset prices, and so on.

The business of large-scale money management, as opposed to running a small trading book, adds complications of its own. Complex calculations have to be performed routinely for thousands of securities, hundreds of portfolios, and their benchmarks in a computationally and operationally feasible fashion. This creates yet another challenge. In order to meaningfully aggregate risk numbers across securities, portfolios, and benchmarks, one has to develop risk methodologies applicable to all types of fixed income securities, trading strategies, and portfolios. This implies creating a *superset* of systematic risk factors influencing all classes of fixed income securities and measuring risk with respect to all of them.

The art of managing risk in fixed income portfolios involves constantly making intelligent trade-offs. It entails finding the fine balance between theoretical knowledge, practical considerations, and computational feasibility. What makes risk management a fascinating discipline is the challenge of mathematically describing real-life phenomena and trying to develop an understanding of the assumptions and conscious trade-offs that are being made. Finally, after conjectures and models are built, it is then possible to test them in different market environments.

1.3.1 Price Discovery

To the uninitiated, it might seem that prices of fixed income securities are known and freely available in the market, just as stock prices are. If in addition to market prices, valuation models are also available to compute fair values of all securities in any given economic environment, numerous risk characteristics for portfolios and securities can be analyzed, including various duration measures and scenario analyses (Chapter 2), Variance/Covariance Value-at-Risk (VaR) (Chapter 4) and Monte-Carlo Simulation Value-at-Risk (Chapter 5). If, in addition to the current market prices, historical time series of prices are available as well, implied duration (Chapter 2) and Historical Simulation VaR (Chapter 5) can be computed as well.

Empirically observing market prices sounds easy in theory. However, since the vast majority of fixed income markets are over-the-counter and are not exchange-traded as stocks are, their *price discovery* is a burdensome operational task. To do a good job, a buy-side company would need to maintain a team of professionals dedicated to researching prices for thousands of fixed income securities with the help of the broker-dealer community. Table 1.2 presents the results of an experiment that illustrates the challenges of the price discovery process. First, several fixed income securities, characterized by varying degrees of liquidity and complexity, were identified. Then four different dealer firms were asked to price these instruments. The results were as expected. For liquid and less complex securities, price quote differentials among dealers were small. For structured or less liquid securities, price quotes varied dramatically across dealers or were unavailable altogether.

TABLE 1.2 Mid-Market Price Marks by Various Dealers for Different Security Types (as of 7/29/98)

Security Type	Description	Coupon	Maturity	Dealer 1	Dealer 2	Dealer 3	Dealer 4
US Treasury Note	Treasury Note	5.75	11/30/02	100.80	100.79	100.78	100.80
Generic MBS	FNMA 30 YR	8.00	05/01/22	104.13	103.90	103.69	104.14
US Corporate Bond	Ameritech Capital	6.55	01/15/28	99.10	98.94	99.22	99.48
Non-agency CMBS	RTC_94-C2-G	8.00	04/25/25	C/P	100.84	C/P	C/P
Whole Loan PAC CMO	BAMS_98-3-2A1	6.50	07/25/13	100.50	100.47	C/P	100.50
ABS - Prepay Sensitive	GT_97-1-B1	7.23	03/15/28	100.22	100.11	100.42	100.16

"C/P" = "Cannot Price"

Due to the fiduciary nature of their business, institutional money managers are required to use market data obtained from an independent third party, and therefore an approach to measuring the quality of market prices is needed. For each security, the historical change in price is decomposed into the components attributable to various risk factors: parallel and nonparallel movements in the yield curve, risk-free return, returns due to changes in credit spreads and implied volatility, and the like. If a substantial component of the price movement is not explained by the actual changes in the relevant risk factors, the following three possibilities exist. First, the security may have under- or outperformed the market. Second, there could have been pricing errors. Third, the parametric risk measures employed in estimating returns due to various systematic factors may have been incorrect. In practice, price discovery is a manual process subject to substantial human, operational, and data problems. Pricing errors have far-reaching consequences which can distort valuation models, impair relative value judgements, and lead to erroneous risk assessments. Regularly monitoring the quality of prices used in portfolio and risk management is therefore vital.

1.3.2 Dynamic Portfolio Characteristics

Dynamic portfolio characteristics tremendously complicate the tasks of measuring and managing risk of fixed income portfolios. Throughout this book, many results and conclusions are influenced by the following crucial considerations.

Impact of time. Risk characteristics of fixed income portfolios change, sometimes dramatically, as the underlying securities age. Irrespective of the market environment, options embedded in fixed income securities decay, durations decrease as bonds approach maturity, mortgage-backed securities and their derivatives become seasoned and experience burnout, becoming less sensitive to prepayments, etc.

Dependency on the economic environment. Risk characteristics of fixed income securities may be drastically different depending on the economic environment they are in. Imagine that interest rates suddenly increased by 100 basis points with all other risk factors being unchanged. First, all cash flows would now be discounted at higher rates. Second, the "in-the-moneyness" of the embedded options would change: options that used to be in-the-money may become out-of-the-money, securities with negative convexities may become positively convex, instruments that used to be highly risky may become virtually option-free (e.g., Planned Amortization Class [PAC] CMOs).

Reinvestment. While the vast majority of risk measures is concerned with analyzing changes in the values of fixed income securities resulting from unexpected market fluctuations, reinvestment risk should not be forgotten. Since, unlike most equities, fixed income securities generate substantial coupon payments subject to reinvestment, the expected total return on the portfolio may be substantially impaired if cash flows have to be reinvested at lower rates than originally planned. Expected rate of return analysis (EROR) (Chapter 2) allows us to measure the impact of time on risk characteristics of fixed income securities and portfolios and assess reinvestment risk.

Path dependency. As if things were not complicated enough, path dependency of certain classes of fixed income securities must be taken into account as well. Two identically structured instruments may have substantially different risk characteristics depending on the *historical path* of their market environments (e.g., barrier options, mortgage-backed securities, etc.).

1.3.3 New Securities, New Structures, and the Absence of Historical Information

Financial markets are constantly evolving. Not only do they become more efficient with advances in option pricing and technology, they are also being constantly extended by new security types and structures. In 1980, for example, mortgage-backed securities and their derivatives emerged. More recently, Brady bonds, U.S. Treasury Inflation-Protected securities (TIPS), various esoteric types of asset-backed securities, CMBS IOs, 144-As, and many other asset classes came to the market. Since newly introduced securities may offer additional return as compared to more developed markets, those who can keep up with recent market innovations may have a significant advantage. However, this entails immediately enhancing valuation models to accommodate the new structures and expanding risk management models to account for auxiliary systematic risk factors. Both valuation and risk management of new financial products are especially challenging given the absence of historical information about them. In the beginning, the tasks of determining the fair value of new securities as well as measuring their risk are more art than science, because traders and portfolio managers have yet to develop intuition regarding their market behavior and there is no historical information to perform any meaningful empirical analysis.

The fixed income risk management paradigm is very different from that employed in the stock market because of the constant introduction of new financial products, absence of relevant historical information, and challenges of price discovery. While the following discussion is closely related to Section 1.2 that deals with the market risk management process, a different angle is used here. The approach to modeling financial risk presented below has become second nature to fixed income practitioners. Thus, instead of attempting to measure the risk of a security directly, a factor-equivalent (replicating) portfolio is created, and its properties are subsequently analyzed. With varying degrees of accuracy that depend on the methodology, cash flow uncertainties and other characteristics of the factor-equivalent portfolio are tailored to resemble those of the original security. Replicating portfolios can be comprised of actual instruments with long and reliable price histories. For instance, the original formulation of RiskMetrics® Variance/Covariance Value-at-Risk (VaR) (Chapter 4) presented each fixed income security as a portfolio of zero-coupon bonds. Unfortunately, replicating fixed income instruments using actual securities is not always intellectually or computationally feasible. For this reason, many modern risk management methodologies use factor-equivalent portfolios, consisting of *imaginary* securities that represent systematic risk factors directly. For example, owning a corporate bond is, to the first-order approximation, equivalent to holding a portfolio of zero-coupon bonds as well as having the exposure to the appropriate corporate credit spread. The market risk of the original security is measured by integrating information about market exposures with estimates about volatilities and correlations of the instruments in the factor-equivalent portfolio.

1.4 STATISTICAL CHALLENGES: RISK MANAGEMENT VERSUS VALUATION

There are two distinct problems faced by investors: *valuation* and *risk management.* Valuation is concerned with determining the *fair value* of a security at a particular moment in time in a specified economic environment. Accurate computation of a security's fair value is contingent on the ability to reverse-engineer its cash flow structure (cash flow uncertainties, optionality, and path-dependency) as a function of systematic risk factors and time. Valuation models start with the current values of a variety of systematic risk factors and use stochastic processes to formulate conjectures about their evolution through time. This enables the generation of cash flow streams in a large number of hypothetical market environments and assessment of the probability associated with each scenario. According to modern option pricing theory, the *fair* price of a security is defined as a *mathematical expectation* of all conceivable discounted future payoffs.

Time series analysis has been widely used in economics and finance ever since it was discovered that univariate ARIMA models often have far better forecasting and explanatory power than extremely complicated multivariate macroeconomic models. For instance, technical analysis uses the past of a univariate time series to predict its future movements and judge relative value. Econometric prepayment models attempt to forecast mortgage prepayments as functions of borrower-specific factors, macroeconomic variables, and time. When describing the future evolution of systematic risk factors, some option-pricing models use time series analysis to statistically estimate parameters of the conjectured stochastic processes. Since valuation models compute the mathematical *expectation* of a price as a function of a large number of stochastic variables, they typically attempt to model as precisely as possible the *bulk* of the probabilistic distribution of future returns and are less concerned with the accuracy of modeling the *tails* of this distribution. Hence the use of less sophisticated time series methods when solving valuation problems.

The fact that valuation models use information about the current economic environment (yield curves, foreign exchange rates, observed market prices, implied volatilities, and various credit spreads) as input makes them *market-state dependent.* This observation provides the most direct and simplest explanation of the need for risk management: Because prices of fixed income securities change as valuation models' inputs fluctuate, the sensitivity of prices to various systematic risk factors as well as the probabilistic behavior of these sources of market risk need to be measured. Thus, once the fair value of a security is determined, traders use their views on the market as well as various relative value considerations to decide whether to go long or short this security. Risk management then comes into the picture in order to assess the risk associated with *unexpected* market moves. At this point, the knowledge of the probability associated with potential losses is combined with the estimates of their magnitude to arrive at a "worst-case loss." Notice that instead of attempting to model as accurately as possible the bulk of future distribution of price changes, risk management is concerned with measuring, mitigating, and controlling large financial losses, that is, modeling the left *tail* of the future distribution of random returns. This need for higher accuracy of modeling tails of probability distributions, in turn, spurred new interest in applied statistical modeling, including ARCH/GARCH, dynamic time series models, and the like.

1.5 EVOLUTION OF RISK MANAGEMENT IDEAS

Valuation and risk management problems are closely related. Many measures of risk rely on the ability to compute fair values of fixed income in a variety of historical and hypothetical economic environments. It is therefore not surprising that the emergence of risk management as a rigorous discipline has coincided with breakthroughs in different aspects of valuation – option pricing theory, interest rate modeling, prepayment modeling, and methods dealing with yield curve estimation. These intellectual advances in valuation, in turn, resulted from the application to finance of progressively sophisticated approaches from econometrics, computational mathematics, and stochastic calculus as well as the development of financial theory.

To set the stage for a more detailed discussion of various risk methodologies in the following chapters, this section provides an overview of the intellectual evolution of risk management. Although changes in prices of fixed income securities were known to have been influenced by dozens of systematic risk factors, as an analytical shortcut, price exposures to each risk factor were initially analyzed in isolation, with all other variables being fixed. This is equivalent to assuming that price fluctuations are driven by a single systematic risk factor. Let us utilize the language of fixed income markets and call this single source of systematic market risk "yield." In this setting, since the entire economic environment manifests itself in the relationship between the current price and the current yield, the ability to calculate the value of a security is equivalent to computing one point on the (unknown) price/yield function (Exhibit 1.1).

In contrast to valuation that deals with computing *fair* values of fixed income securities, risk management is concerned with estimating potential losses resulting from large unexpected market movements. This entails knowing how the price changes in response to *any* hypothetical change in yield. In other words, to be able to judge risk, the entire price/yield function of each instrument is needed. For a variety of computational and conceptual reasons, the timely and accurate construction of price/yield functions of all fixed income securities was not possible when investors first starting quantifying financial risks. Another method was needed to estimate risk without constructing the entire price/yield curve. The application of Taylor series expansions provided insight into the price sensitivity of fixed income securities. The first-order approximation of the price/yield function became known as *delta* or, converted into an elasticity measure, *duration,* while the second-order approximation was called *delta-gamma* or *duration-convexity* (Exhibit 1.2).

EXHIBIT 1.1 Ability to Compute Fair Price = One Point on the Price/Yield Curve

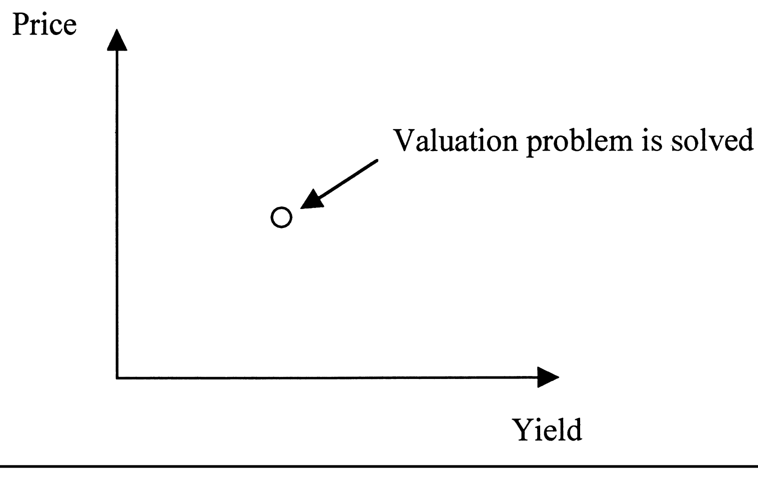
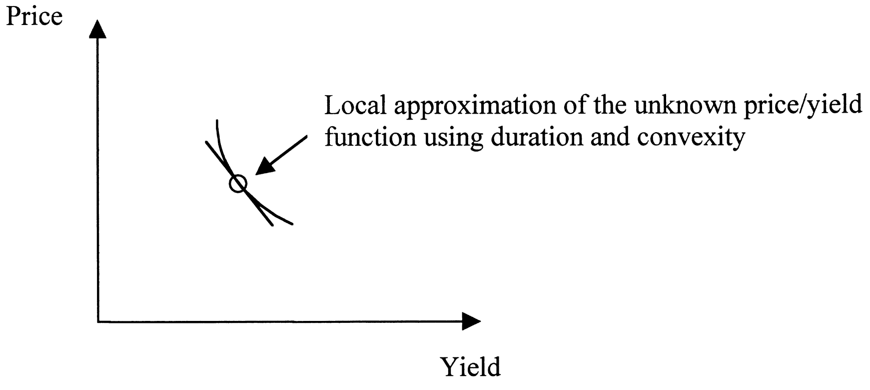


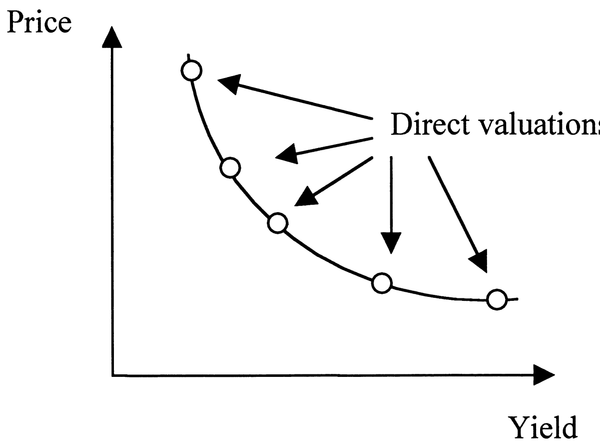
EXHIBIT 1.2 Duration and Convexity: Local Approximations of the Unknown Price/Yield Function



The first- and second-order approximations of the price/yield function may not be accurate predictors of price changes when the underlying changes in the systematic risk factors are large. In general, the more nonlinear the price/yield function is, the poorer the approximation. Unfortunately, judging the accuracy of the various approximations of the price/yield function without explicitly sketching its actual shape is difficult. Scenario analysis, an approach to constructing price/functions via numerous direct revaluations of a security in various economic environments, became an important step in the evolution of risk management ideas. While it can be difficult to perform scenario analysis when the number of risk factors is large, if price is assumed to be a function of a single risk factor, scenario analysis provides a rather comprehensive (deterministic) representation of market risk (Exhibit 1.3).

Knowledge about the nonstochastic price sensitivity of fixed income securities and portfolios to changes in systematic risk factors is, by itself, insufficient for understanding financial risk. Thus, price distributions of fixed income portfolios and securities can be constructed through combining deterministic parametric measures (Chapter 2) with forecasts of probability distribution of systematic risk factors (correlations and volatilities, Chapter 3). VaR and other probabilistic measures of risk discussed in Chapters 4 and 5 describe certain statistical

EXHIBIT 1.3 Scenario Analysis: Explicitly Constructing the Price/Yield Function



properties of probability density functions of price changes (Exhibit 1.4).

Exhibit 1.5 portrays the intellectual evolution of risk measures and methodologies. Using this diagram, the reader can track the application of progressively more sophisticated approaches to risk management as investors were coping with increasingly complex products and markets and gaining deeper understanding of financial risk. By presenting risk measures according to the way they emerged, we have attempted to help the reader develop a broad perspective on risk management as well as appreciation for its complexity and advancement over the years.

EXHIBIT 1.4 Price/Yield Function + Probability Distribution of Risk Factors = Comprehensive Risk Measures

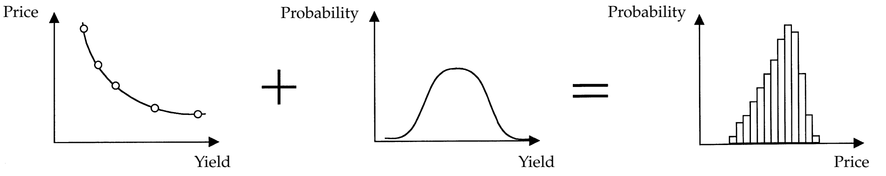
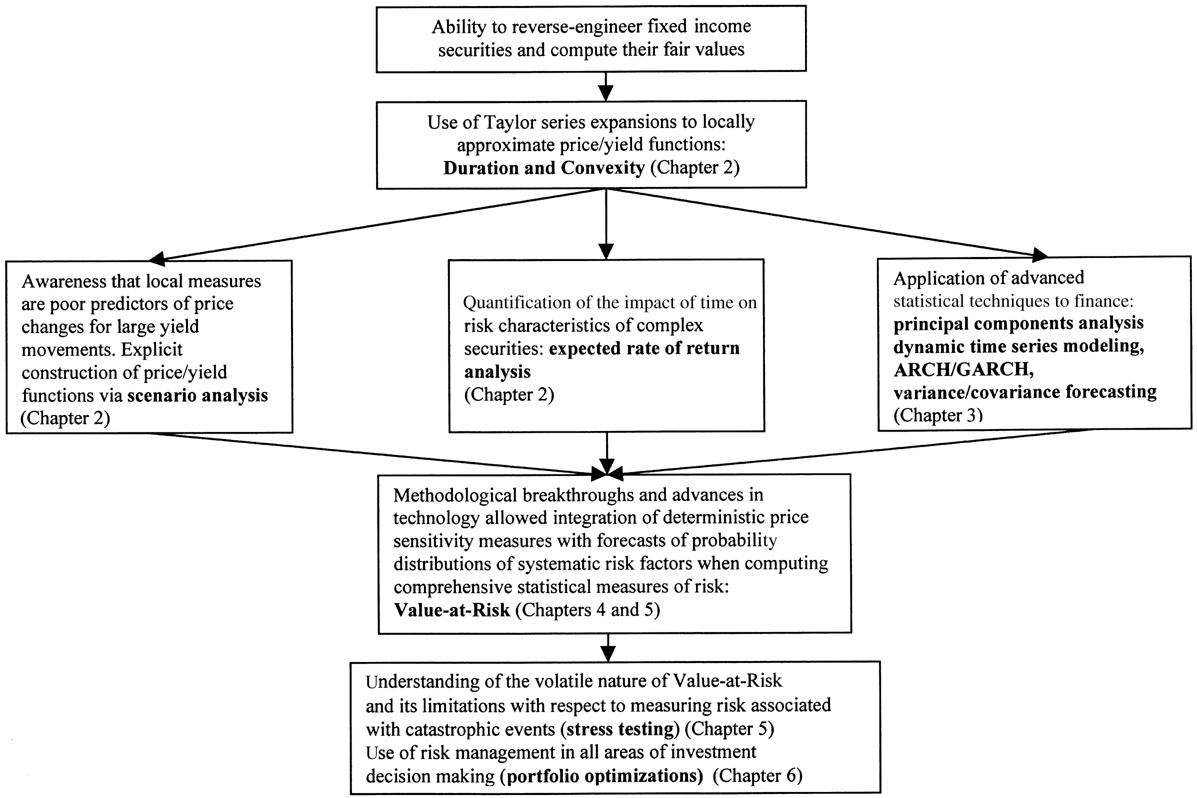


EXHIBIT 1.5 Evolution of Risk Management Ideas



ENDNOTES

1. See Jorion, 1999.
2. See Litterman and Winkelmann, 1996.
3. See "BARRA Refocuses Product Strategy" (BARRA, Inc. Press Release, April 19, 1999).
4. This claim may seem counterintuitive given that on-the-run (OTR) U.S. Treasury securities significantly outperformed off-the-run securities during the 1998 credit and liquidity crisis. Market participants typically buy off-the-run Treasuries for buy-and-hold purposes or as parts of asset swap strategies. Conversely, on-the-run securities are most typically used to quickly change duration. The extreme liquidity of on-the-runs made them particularly valuable during crises, since they permitted investors to rapidly adjust positions in size, which caused the outperformance of OTR Treasuries.
5. Some attribute LTCM's demise to its use of portfolio optimizations based on VaR that was computed over very recent historical data (see Jorion, 1999).
6. Discussion of portfolio insurance is based on Taleb, 1997.
7. Description of option-adjusted spread models is presented in Chapter 2.
8. See Section 1.3.1 on price discovery.
9. The absolute risk of a portfolio can be also thought of as the relative risk of a portfolio vis-à-vis a cash benchmark.