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Introduction

Our main goal is modeling credit risk for measuring portfolio risk and for pricing defaultable bonds, credit derivatives, and other securities exposed to credit risk. We present critical assessments of alternative conceptual approaches to pricing and measuring the financial risks of credit-sensitive instruments, highlighting the strengths and weaknesses of current practice. We also review recent developments in the markets for risk, especially credit risk, and describe certain enhancements to current pricing and management practices that we believe may better position financial institutions for likely innovations in financial markets.

We have in mind three complementary audiences. First, we target those whose key business responsibilities are the measurement and control of financial risks. A particular emphasis is the risk associated with large portfolios of over-the-counter (OTC) derivatives; financial contracts such as bank loans, leases, or supply agreements; and investment portfolios or broker-dealer inventories of securities. Second, given a significant focus here on alternative conceptual and empirical approaches to pricing credit risk, we direct this study to those whose responsibilities are trading or marketing products involving significant credit risk. Finally, our coverage of both pricing and risk measurement will hopefully be useful to academic researchers and students interested in these topics.

The recent notable increased focus on credit risk can be traced in part to the concerns of regulatory agencies and investors regarding the risk exposures of financial institutions through their large positions in OTC derivatives and to the rapidly developing markets for price- and credit-sensitive instruments that allow institutions and investors to trade these risks. At a conceptual level, market risk—the risk of changes in the market value of a firm's portfolio of positions—includes the risk of default or fluctuation in the credit quality of one's counterparties. That is, credit risk is one source of market risk. An obvious example is the common practice among broker-dealers in corporate bonds of marking each bond daily so as to reflect changes in credit spreads. The associated revaluation risk is normally captured in market risk-management systems.

At a more pragmatic level, both the pricing and management of credit risk introduces some new considerations that trading and risk-management systems of many financial institutions are not currently fully equipped to handle. For example, credit risks that are now routinely measured as components of market risks (e.g., changes in corporate bond yield spreads) may be recognized, while possibly offsetting credit risks embedded in certain less liquid credit-sensitive positions, such as loan guarantees and irrevocable lines of credit, may not be captured. In particular, the aggregate credit risk of a diverse portfolio of instruments is often not measured effectively.

Furthermore, there are reasons to track credit risk, by counterparty, that go beyond the contribution made by credit risk to overall market risk. In credit markets, two important market imperfections, *adverse selection* and *moral hazard*, imply that there are additional benefits from controlling counterparty credit risk and limiting concentrations of credit risk by industry, geographic region, and so on. Current practice often has the credit officers of a financial institution making *zero-one* decisions. For instance, a proposed increase in the exposure to a given counterparty is either declined or approved. If approved, however, the increased credit exposure associated with such transactions is sometimes not "priced" into the transaction. That is, trading desks often do not fully adjust the prices at which they are willing to increase or decrease exposures to a given counterparty in compensation for the associated changes in credit risk. Though current practice is moving in the direction of pricing credit risk into an increasing range of positions, counterparty by counterparty, the current state of the art with regard to pricing models has not evolved to the point that this is done systematically.

The informational asymmetries underlying bilateral financial contracts elevate *quality pricing* to the front line of defense against unfavorable accumulation of credit exposures. If the credit risks inherent in an instrument are not appropriately priced into a deal, then a trading desk will either be losing potentially desirable business or accumulating credit exposures without full compensation for them.

The information systems necessary to quantify most forms of credit risk differ significantly from those appropriate for more traditional forms of market risk, such as changes in the market prices or rates. A natural and prevalent attitude among broker-dealers is that the market values of open positions should be re-marked each day, and that the underlying price risk can be offset over relatively short time windows, measured in days or weeks. For credit risk, however, offsets are not often as easily or cheaply arranged. The credit risk on a given position frequently accumulates over long time horizons, such as the maturity of a swap. This is not to say that credit risk is a distinctly long-term phenomenon. For example, settlement risk can be significant, particularly for foreign-exchange products. (Conversely, the market risk of default-free positions is not always restricted to short time windows. Illiquid positions, or long-term speculative positions, present long-term price risk.)

On top of distinctions between credit risk and market price risk that can be made in terms of time horizons and liquidity, there are important methodological differences. The information necessary to estimate credit risk, such as the likelihood of default of a counterparty and the extent of loss given default, is typically quite different, and obtained from different sources, than the information underlying market risk, such as price volatility. (Our earlier example of the risk of changes in the spreads of corporate bonds is somewhat exceptional, in that the credit risk is more easily offset, at least for liquid bonds, and is also more directly captured through yield-spread volatility measures.)

Altogether, for reasons of both methodology and application, it is natural to expect the development of special pricing and risk-management systems for credit risk and separate systems for market price risk. Not surprisingly, these systems will often be developed and operated by distinct specialists. This does not suggest that the two systems should be entirely disjoint. Indeed, the economic factors underlying changes in credit risk are often correlated over time with those underlying more standard market risks. For instance, we point to substantial evidence that changes in Treasury yields are correlated with changes in the credit spreads between the yields on corporate and Treasury bonds. Consistent with theory, low-quality corporate bond spreads are correlated with equity returns and equity volatility. Accordingly, for both pricing and risk measurement, we seek frameworks that allow for interaction among market and credit risk factors. That is, we seek integrated pricing and risk-measurement systems. A firm's ultimate appetite for risk and the firmwide capital available to buffer financial risk are not specific to the source of the risk.

1.1. A Brief Zoology of Risks

We view the risks faced by financial institutions as falling largely into the following broad categories:

- *Market risk*—the risk of unexpected changes in prices or rates.
- *Credit risk*—the risk of changes in value associated with unexpected changes in credit quality.
- *Liquidity risk*—the risk that the costs of adjusting financial positions will increase substantially or that a firm will lose access to financing.
- *Operational risk*—the risk of fraud, systems failures, trading errors (e.g., deal mispricing), and many other internal organizational risks.

- *Systemic risk*—the risk of breakdowns in marketwide liquidity or chain-reaction default.

Market price risk includes the risk that the degree of volatility of market prices and of daily profit and loss will change over time. An increase in volatility, for example, increases the prices of option-embedded securities and the probability of a portfolio loss of a given amount, other factors being held constant. Within market risk, we also include the risk that relationships among different market prices will change. This, aside from its direct impact on the prices of cross-market option-embedded derivatives, involves a risk that diversification and the performance of hedges can deteriorate unexpectedly.

Credit risk is the risk of default or of reductions in market value caused by changes in the credit quality of issuers or counterparties. Figure 1.1 illustrates the credit risk associated with changes in spreads on corporate debt at various maturities. These changes, showing the direct effects of changes in credit quality on the prices of corporate bonds, also signal likely changes in the market values of OTC derivative positions held by corporate counterparties.

Liquidity risk involves the possibility that bid-ask spreads will widen dramatically in a short period of time or that the quantities that counterparties are willing to trade at given bid-ask spreads will decline substantially, thereby reducing the ability of a portfolio to be quickly restructured in times of financial stress. This includes the risk that severe cash flow stress forces dramatic balance-sheet reductions, selling at bid prices and/or buying at ask prices, with accompanying losses or financial distress. Examples of recent experiences of severe liquidity risk include

- In 1990, the Bank of New England faced insolvency, in part because of potential losses and severe illiquidity on its foreign exchange and interest-rate derivatives.
- Drexel Burnham Lambert—could they have survived with more time to reorganize?
- In 1991, Salomon Brothers faced, and largely averted, a liquidity crisis stemming from its Treasury bond “scandal.” Access to both credit and customers was severely threatened. Careful public relations and efficient balance-sheet reductions were important to survival.
- In 1998, a decline in liquidity associated with the financial crises in Asia and Russia led (along with certain other causes) to the collapse in values of several prominent hedge funds, including Long-Term Capital Management, and sizable losses at many major financial institutions.

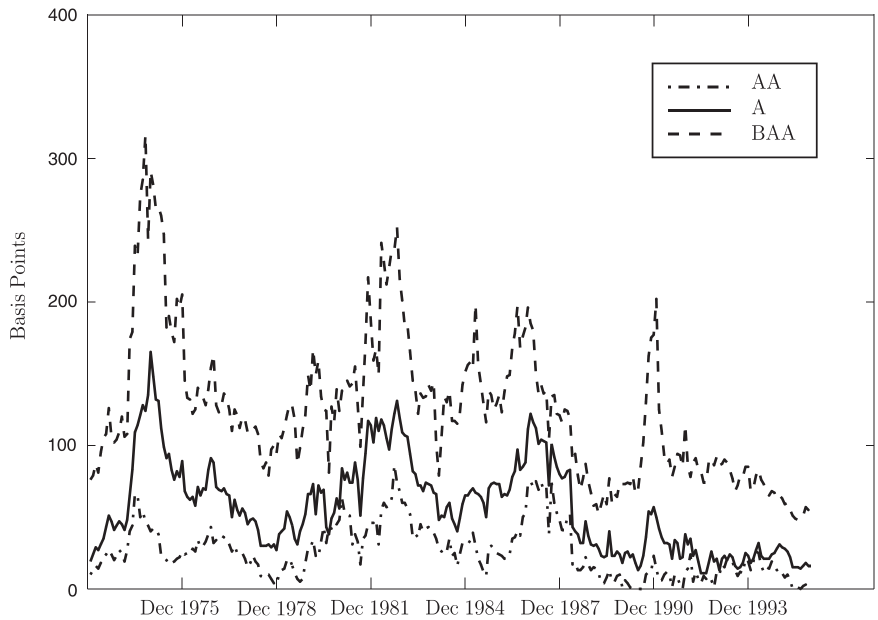

Figure 1.1. *Corporate bond spreads. (Source: Lehman Brothers.)*

- In late 2001, Enron revealed accounting discrepancies that led many counterparties to reduce their exposures to Enron and to avoid entering into new positions. This ultimately led to Enron's default.

Changes in liquidity can also be viewed as a component of market risk. For example, Figure 1.2 shows that Japanese bank debt (JBD) sometimes traded through (was priced at lower yields than apparently more creditworthy) Japanese government bonds (JGBs), presumably indicating the relatively greater liquidity of JBDs compared to JGBs. (Swap-JGB spreads remained positive.)

Systemic risk involves the collapse or dysfunctionality of financial markets, through multiple defaults, "domino style," or through widespread disappearance of liquidity. In order to maintain a narrow focus, we will have relatively little to say about systemic risk, as it involves (in addition to market, credit, and liquidity risk) a significant number of broader conceptual issues related to the institutional features of financial systems. For treatments of these issues, see Eisenberg (1995), Rochet and Tirole (1996), and Eisenberg and Noe (1999). We stress, however, that co-movement in market prices—nonzero correlation—need not indicate systemic risk per se. Rather, co-movements in market prices owing to normal economic

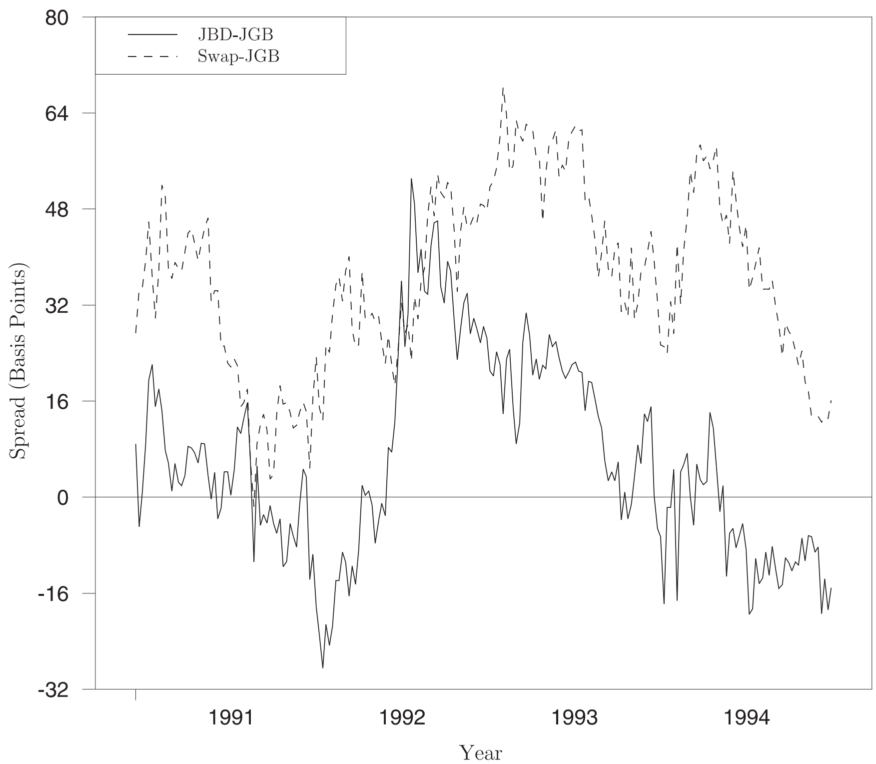

Figure 1.2. *Japanese bank debt trading through government bonds.*

fluctuations are to be expected and should be captured under standard pricing and risk systems.

Finally, *operational risk*, defined narrowly, is the risk of mistakes or breakdowns in the trading or risk-management operations. For example: the fair market value of a derivative could be miscalculated; the hedging attributes of a position could be mistaken; market risk or credit risk could be mismeasured or misunderstood; a counterparty or customer could be offered inappropriate financial products or incorrect advice, causing legal exposure or loss of goodwill; a "rogue trader" could take unauthorized positions on behalf of the firm; or a systems failure could leave a bank or dealer without the effective ability to trade or to assess its current portfolio.

A broader definition of operational risk would include any risk not already captured under market risk (including credit risk) and liquidity risk. Additional examples would then be:

- *Regulatory and legal risk*—the risk that changes in regulations, accounting standards, tax codes, or application of any of these, will result in unforeseen losses or lack of flexibility. This includes the risk that the legal basis for financial contracts will change unexpectedly, as occurred with certain U.K. local authorities' swap positions in the early 1990s. The risk of a precedent-setting failure to recognize netting on OTC derivatives could have severe consequences. The significance of netting is explained in Chapter 12.

- *Inappropriate counterparty relations*—including failure to disclose information to the counterparty, to ensure that the counterparty's trades are authorized and that the counterparty has the ability to make independent decisions about its transactions, and to deal with the counterparty without conflict of interest.
- *Management errors*—including inappropriate application of hedging strategies or failures to monitor personnel, trading positions, and systems and failure to design, approve, and enforce risk-control policies and procedures.

Some, if not a majority, of the major losses by financial institutions that have been highlighted in the financial press over the past decade are the result of operational problems viewed in this broad way and not directly a consequence of exposure to market or credit risks. Examples include major losses to Barings and to Allied Irish Bank through rogue trading, and the collapse of Enron after significant accounting discrepancies were revealed.

Our focus in this book is primarily on the market and, especially, credit risk underlying pricing and risk-measurement systems. Given the relatively longer holding periods often associated with credit-sensitive instruments and their relative illiquidity, liquidity risk is also addressed—albeit often less formally. Crouhy et al. (2001) offer a broad treatment of risk management for financial institutions with a balanced coverage of market, credit, and operational risk, including a larger focus on management issues than we offer here.

1.2. Organization of Topics

We organize subsequent chapters into several major topic areas:

- Economic principles of risk management (Chapter 2).
- Single-issuer default and transition risk (Chapters 3 and 4).
- Valuation of credit risk (Chapters 5–9).
- Default correlation and related portfolio valuation issues (Chapters 10 and 11).
- The credit risk in OTC derivatives positions and portfolio credit risk measurement (Chapters 12 and 13).

We begin our exploration of credit risk in Chapter 2, with a discussion of the economic principles guiding credit risk management for financial firms, along with an overview of some procedural risk-management issues. As a set of activities, risk management by a financial firm may involve: (1) measuring the extent and sources of exposure; (2) charging each position a cost of capital appropriate to its risk; (3) allocating scarce risk capital to traders and profit centers; (4) providing information on the firm's financial integrity to outside parties, such as investors, rating agencies, and regulators; (5) evaluating the performance of profit centers in light of the risks taken to achieve profits; and (6) mitigating risk by various means and policies. An important objective that applies specifically to credit risk is assigning and enforcing counterparty default exposure limits. Chapter 2 also provides an assessment of several measures of market and credit risk, based on such criteria as how closely they are related to the key economic costs of financial risk or how easily measures of risk at the level of individual units or desks can be meaningfully aggregated into an overall measure of risk for the firm. We also discuss here, at an introductory level, the challenges that arise in attempting to implement these measures and aggregate market and credit risks.

In developing frameworks for the measurement and pricing of credit risks, our initial focus is the modeling of *default risk* and *ratings-transitions risk*. Chapter 3 introduces a convenient and tractable class of models of the default process for a given counterparty that is based on the concept of *default intensity*. Intuitively, the default intensity of a counterparty measures the conditional likelihood that it will default over the next small interval of time, given that it has yet defaulted and given all other available information. Here, we also review the historical experience with corporate defaults in the United States, and relate these experiences to calibrations of models of default. Similar issues regarding ratings-transition risk—the risk that a counterparty will have its credit rating upgraded or downgraded—are taken up in Chapter 4. Both of these chapters explore alternatives for a computationally tractable algorithm for simulating future defaults and ratings transitions, an essential ingredient of credit risk measurement and pricing systems.

These two foundational modeling chapters are followed by a series of chapters that develop models for, and empirical evidence regarding, the pricing of defaultable instruments. Chapter 5 provides an overview of alternative conceptual approaches to the valuation of securities in the presence of default risk. Initially, we focus on the most basic instrument—a defaultable zero-coupon bond—in order to compare and contrast some of the key features of alternative models. We review two broad classes of models: (1) *reduced-form*, those that assume an *exogenously* specified process for the migration of default probabilities, calibrated to historical or current market data; and (2) *structural*, those based directly on the issuer's ability or willingness to pay its liabilities. This second class is usually framed around a stochastic model of variation in assets relative to liabilities. Most pricing models and frameworks for inferring default probabilities from market data adopt one of these two approaches. A review of their conceptual underpinnings will prove useful in addressing many other issues.

Chapter 5 also includes a discussion of the differences between *risk-neutral* and *actual* default probabilities. Our discussion of default processes in Chapters 3 and 4 and the mappings of these models to historical experience focus on actual probabilities. Virtually all pricing models in use in the financial industry and studied by academics are based instead on risk-neutral probabilities. That is, building on the pathbreaking result of Black and Scholes (1973) and Merton (1974) showing that *plain-vanilla* (conventional) equity options can be priced, given the underlying price, as though investors are neutral to risk, one may compute the market values of future cash flows, possibly from defaultable counterparties, from the expectation of discounted cash flows, under risk-neutral probabilities.

Chapter 6 discusses the pricing of corporate bonds in more detail, paying particular attention to the practical and empirical aspects of model implementation. We begin here with a discussion of another key component of default risk: the recovery in the event of default. Though bond covenants are often clear about the payoff owed by the defaulting counterparty, we emphasize that renegotiation out of bankruptcy, as well as in bankruptcy courts, does not always result in strict adherence to the terms of bond covenants. Faced with the real-world complexity of default settlements, a variety of tractable approximations to the outcomes of settlement processes have been used to develop simple pricing models. We illustrate some of the practical implications of different recovery assumptions for the pricing of defaultable securities.

For certain defaultable instruments, an important indicator of credit quality is the credit rating of the counterparty. Credit ratings are provided by major independent rating agencies such as Moody's and Standard & Poor's. In addition, many financial institutions assign internal credit ratings. Ratings are often given as discrete indicators of quality, so a transition from one rating to another could, if not fully anticipated, introduce significant *gapping* risk into market prices, that is, the risk of significant discrete moves in market prices as a rating is changed. The formal introduction of this gapping risk into pricing systems presents new challenges, which are reviewed briefly at the end of Chapter 6.

Drawing upon our discussions of default, recovery, and dynamic models of the prices of reference securities (e.g., Treasuries or swaps), we turn in Chapter 7 to an overview of alternative empirical models of corporate and sovereign yield spreads. We also review in this chapter some standard term-structure models for the time-series behavior of the benchmark yield curves from which defaultable bonds are spread. Sovereign bonds present their own complications because of the more diverse set of possible credit events, including various types of restructuring, changes in political regimes, and so on, and the nature of the underlying risk factors that influence default and restructuring decisions. We discuss the nature of the credit risks inherent in sovereign bonds and review the evidence on default and recovery. Additionally, we present an in-depth analysis of a model for pricing sovereign debt with an empirical application to Russian bonds leading up to the default in August 1998.

Next, we direct our attention to the rapidly growing markets for credit derivatives. Among these new derivatives, credit swaps have been the most widely traded and are taken up in Chapter 8. An important feature of credit swaps is that the exchange of cash flows between the counterparties is explicitly contingent on a credit event, such as default by a particular issuer. Indeed, the most basic default swap is essentially insurance against loss of principal on a defaulting loan or bond. The chapter focuses on the structure of these contracts as well as on pricing models.

Chapter 9 treats the valuation of options for which the underlying security is priced at a yield spread. An obvious example is a spread option, conveying the right to put a given fixed-income security, such as a corporate or sovereign bond, at a given spread to a reference bond, such as a Treasury note. A traditional lending facility, for example, an irrevocable line of credit, can also be viewed in these terms. The chapter also treats callable and convertible corporate debt, examining the manner in which both interest-rate risk and credit risk jointly determine the value of the embedded options.

In order to address instruments with payoffs that are sensitive to the joint credit risks of multiple issuers, we consider alternative conceptual formulations of default correlation in Chapter 10.

One of the most important recent developments in the securitization of credit risk is the growing issuance of *collateralized debt obligations* (CDOs). The cash flows of loans or bonds of various issuers are pooled and then tranched by priority into a hierarchy of claims, much as with the earlier development of collateralized mortgage obligations. The pricing of CDOs is presented in Chapter 11, along with a critical discussion of how rating agencies are assessing the credit risks of these relatively complex instruments.

Chapter 12 examines the impact of credit risk on OTC derivatives. The key issues here are exposure measurement and the adjustment for credit risk of valuations based on midmarket pricing systems. For many such derivatives, such as forwards and interest-rate swaps, credit risk is two sided: either counterparty may default and, depending on market conditions, either counterparty may be at risk of loss from default by the other. For example, with a plain-vanilla at-market interest-rate swap,[1] the market

[1] A standard arrangement is for counterparty A to pay counterparty B a fixed coupon, say semiannually, in return for receiving a floating payment at the 6-month London Interbank Offer Rate (LIBOR) rate, also every 6 months. Payments are based on an underlying notional amount of principal. No money changes hands at the inception of an at-market swap.

value of the swap at the inception date is zero. Going forward, if interest rates generally rise, then the swap goes *in the money* to the receive-floating side, whereas if rates fall then the swap has positive value to the pay-floating side. Since, over the life of the swap, rates may rise and fall, the credit qualities of both counterparties are relevant for establishing the market value of a swap.

Chapter 13 addresses integrated market and credit risk measurement for large portfolios. We provide several examples of the risk measurement of portfolios of option and loan positions. In developing the market risk component, we address the implications for risk measurement of alternative parameterizations of the risk factors driving portfolio returns. In particular, we explore the implications of changes in volatility (*stochastic volatility*) and of the possibility of sudden jumps in prices for the measurement of market risk. Additionally, we review the *delta-gamma* approach to approximating the prices of OTC derivatives and discuss its reliability for revaluing derivative portfolios in risk measurement. Finally, through our examples, we discuss the use of computationally efficient methods for capturing the sensitivity of derivative prices to underlying prices and to changes in credit quality and default. We contrast the types of portfolios whose profit-and-loss *tail risks* are driven largely by changes in credit quality from types of portfolios whose tail losses are mainly a property of exposure to market prices and rates.

Appendix A presents an overview of *affine* models, a parametric class of Markov jump diffusions that is particularly tractable for valuation and risk modeling in many of the settings that are encountered in this book, including the dynamics of the term structure of interest rates, stochastic volatility and jump risk in asset returns, option valuation, and intensity-based models of default probabilities and default correlation risk. Appendix B reviews alternative approaches to estimating the parameters of the affine models overviewed in Appendix A. Appendix C outlines an approach to modeling term structures of credit spreads that is based on forward-rate models in the spirit of Heath, Jarrow, and Morton (1992).