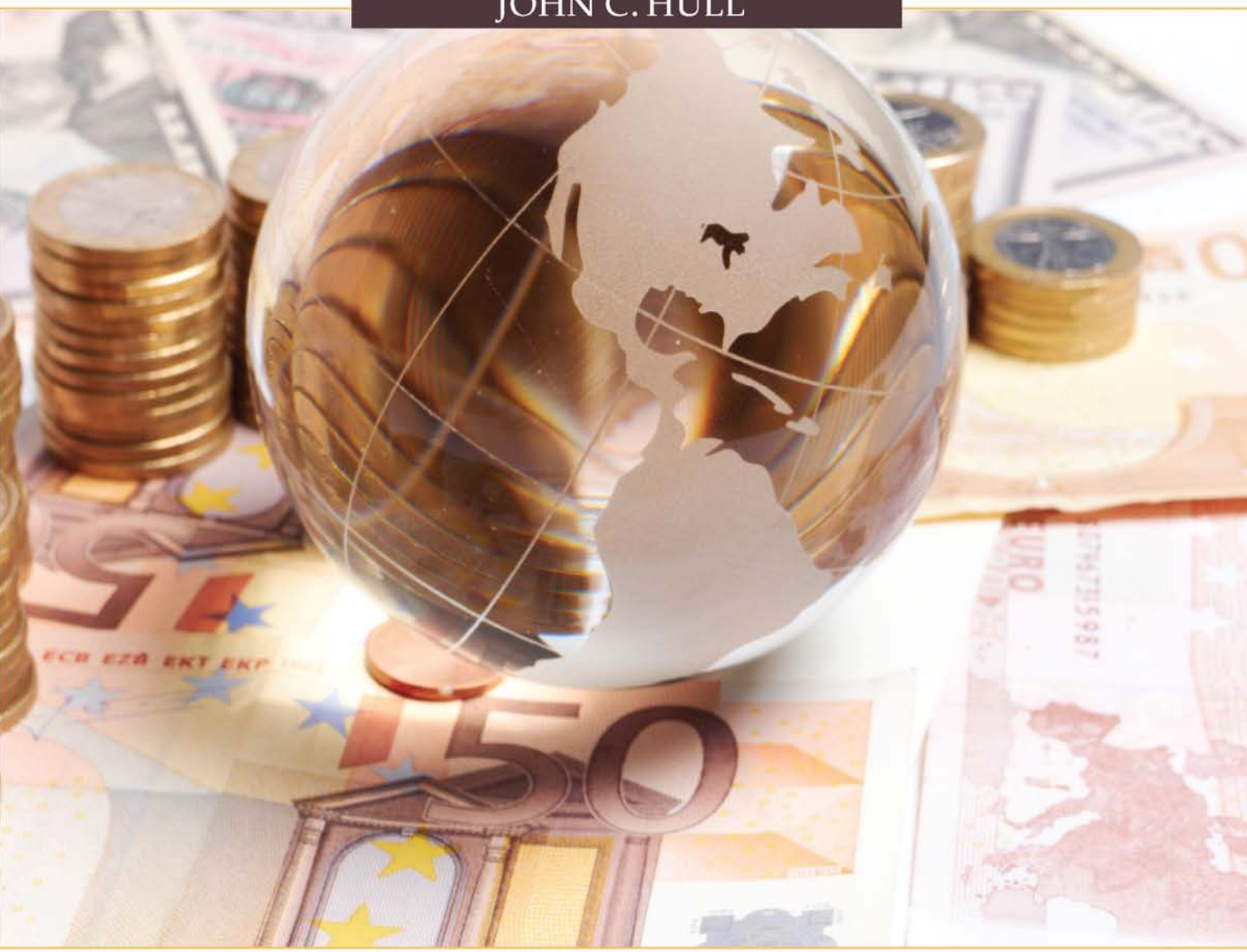
Options, Futures, and Other Derivatives

TENTH EDITION

JOHN C. HULL



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To Michelle

CONTENTS IN BRIEF

List of Business Snapshots ..... *xviii*
List of Technical Notes ..... *xix*
Preface ..... *xx*
1. Introduction 1
2. Futures markets and central counterparties 24
3. Hedging strategies using futures 49
4. Interest rates 77
5. Determination of forward and futures prices 107
6. Interest rate futures 135
7. Swaps 155
8. Securitization and the credit crisis of 2007 184
9. XVAs 199
10. Mechanics of options markets 209
11. Properties of stock options 231
12. Trading strategies involving options 252
13. Binomial trees 272
14. Wiener processes and Itô's lemma 300
15. The Black–Scholes–Merton model 319
16. Employee stock options 352
17. Options on stock indices and currencies 365
18. Futures options and Black's model 381
19. The Greek letters 397
20. Volatility smiles 430
21. Basic numerical procedures 449
22. Value at risk and expected shortfall 493
23. Estimating volatilities and correlations 520
24. Credit risk 543
25. Credit derivatives 569
26. Exotic options 596
27. More on models and numerical procedures 622
28. Martingales and measures 652
29. Interest rate derivatives: The standard market models 670
30. Convexity, timing, and quanto adjustments 689
31. Equilibrium models of the short rate 702
32. No-arbitrage models of the short rate 715
33. HJM, LMM, and multiple zero curves 738
34. Swaps Revisited 757
35. Energy and commodity derivatives 772
36. Real options 789
37. Derivatives mishaps and what we can learn from them 803
Glossary of terms 815
DerivaGem software 838
Major exchanges trading futures and options 843
Tables for $N(x)$ 844
Credits 846
Author index 847
Subject index 851

Contents

List of Business Snapshots ..... **xviii**

List of Technical Notes ..... **xix**

Preface ..... **xx**

Chapter 1. Introduction **1**

1.1 Exchange-traded markets 2
1.2 Over-the-counter markets 3
1.3 Forward contracts 6
1.4 Futures contracts 8
1.5 Options 8
1.6 Types of traders 11
1.7 Hedgers 11
1.8 Speculators 14
1.9 Arbitrageurs 16
1.10 Dangers 17
Summary 18
Further reading 19
Practice questions 19
Further questions 21

Chapter 2. Futures markets and central counterparties **24**

2.1 Background 24
2.2 Specification of a futures contract 26
2.3 Convergence of futures price to spot price 28
2.4 The operation of margin accounts 29
2.5 OTC markets 32
2.6 Market quotes 36
2.7 Delivery 38
2.8 Types of traders and types of orders 39
2.9 Regulation 40
2.10 Accounting and tax 41
2.11 Forward vs. futures contracts 43
Summary 44
Further reading 45
Practice questions 45
Further questions 47

Chapter 3. Hedging strategies using futures **49**

3.1 Basic principles 49
3.2 Arguments for and against hedging 51
3.3 Basis risk 54
3.4 Cross hedging 58

3.5 Stock index futures ... 62
3.6 Stack and roll ... 68
Summary ... 70
Further reading ... 70
Practice questions ... 71
Further questions ... 73
Appendix: Capital asset pricing model ... 75

Chapter 4. Interest rates ... 77
4.1 Types of rates ... 77
4.2 Swap rates ... 79
4.3 The risk-free rate ... 80
4.4 Measuring interest rates ... 81
4.5 Zero rates ... 84
4.6 Bond pricing ... 84
4.7 Determining zero rates ... 85
4.8 Forward rates ... 89
4.9 Forward rate agreements ... 92
4.10 Duration ... 94
4.11 Convexity ... 98
4.12 Theories of the term structure of interest rates ... 99
Summary ... 101
Further reading ... 102
Practice questions ... 102
Further questions ... 105

Chapter 5. Determination of forward and futures prices ... 107
5.1 Investment assets vs. consumption assets ... 107
5.2 Short selling ... 108
5.3 Assumptions and notation ... 109
5.4 Forward price for an investment asset ... 110
5.5 Known income ... 113
5.6 Known yield ... 115
5.7 Valuing forward contracts ... 115
5.8 Are forward prices and futures prices equal? ... 117
5.9 Futures prices of stock indices ... 118
5.10 Forward and futures contracts on currencies ... 120
5.11 Futures on commodities ... 124
5.12 The cost of carry ... 126
5.13 Delivery options ... 127
5.14 Futures prices and expected future spot prices ... 127
Summary ... 130
Further reading ... 131
Practice questions ... 131
Further questions ... 133

Chapter 6. Interest rate futures ... 135
6.1 Day count and quotation conventions ... 135
6.2 Treasury bond futures ... 138
6.3 Eurodollar futures ... 143
6.4 Duration-based hedging strategies using futures ... 148
6.5 Hedging portfolios of assets and liabilities ... 150
Summary ... 150
Further reading ... 151

Practice questions....151
Further questions....153

Chapter 7. Swaps....155
7.1 Mechanics of interest rate swaps....156
7.2 Day count issues....161
7.3 Confirmations....162
7.4 The comparative-advantage argument....162
7.5 Valuation of interest rate swaps....165
7.6 How the value changes through time....168
7.7 Fixed-for-fixed currency swaps....169
7.8 Valuation of fixed-for-fixed currency swaps....172
7.9 Other currency swaps....174
7.10 Credit risk....175
7.11 Credit default swaps....176
7.12 Other types of swaps....177
Summary....179
Further reading....179
Practice questions....179
Further questions....182

Chapter 8. Securitization and the credit crisis of 2007....184
8.1 Securitization....184
8.2 The U.S. housing market....188
8.3 What went wrong?....192
8.4 The aftermath....194
Summary....195
Further reading....196
Practice questions....197
Further questions....197

Chapter 9. XVAs....199
9.1 CVA and DVA....199
9.2 FVA and MVA....202
9.3 KVA....205
9.4 Calculation issues....206
Summary....207
Further reading....207
Practice questions....208
Further questions....208

Chapter 10. Mechanics of options markets....209
10.1 Types of options....209
10.2 Option positions....211
10.3 Underlying assets....213
10.4 Specification of stock options....215
10.5 Trading....219
10.6 Commissions....220
10.7 Margin requirements....221
10.8 The options clearing corporation....222
10.9 Regulation....223
10.10 Taxation....223
10.11 Warrants, employee stock options, and convertibles....225
10.12 Over-the-counter options markets....226
Summary....226

Further reading ... 227
Practice questions ... 227
Further questions ... 229

Chapter 11. Properties of stock options ... 231
11.1 Factors affecting option prices ... 231
11.2 Assumptions and notation ... 235
11.3 Upper and lower bounds for option prices ... 236
11.4 Put–call parity ... 238
11.5 Calls on a non-dividend-paying stock ... 241
11.6 Puts on a non-dividend-paying stock ... 244
11.7 Effect of dividends ... 246
Summary ... 247
Further reading ... 248
Practice questions ... 248
Further questions ... 250

Chapter 12. Trading strategies involving options ... 252
12.1 Principal-protected notes ... 252
12.2 Trading an option and the underlying asset ... 254
12.3 Spreads ... 256
12.4 Combinations ... 264
12.5 Other payoffs ... 267
Summary ... 268
Further reading ... 269
Practice questions ... 269
Further questions ... 270

Chapter 13. Binomial trees ... 272
13.1 A one-step binomial model and a no-arbitrage argument ... 272
13.2 Risk-neutral valuation ... 276
13.3 Two-step binomial trees ... 278
13.4 A put example ... 281
13.5 American options ... 282
13.6 Delta ... 283
13.7 Matching volatility with u and d ... 284
13.8 The binomial tree formulas ... 286
13.9 Increasing the number of steps ... 286
13.10 Using DerivaGem ... 287
13.11 Options on other assets ... 288
Summary ... 291
Further reading ... 292
Practice questions ... 293
Further questions ... 294
Appendix: Derivation of the Black–Scholes–Merton option-pricing formula from a binomial tree ... 296

Chapter 14. Wiener processes and Itô's lemma ... 300
14.1 The Markov property ... 300
14.2 Continuous-time stochastic processes ... 301
14.3 The process for a stock price ... 306
14.4 The parameters ... 309
14.5 Correlated processes ... 310
14.6 Itô's lemma ... 311
14.7 The lognormal property ... 312

Summary 313
Further reading 314
Practice questions 314
Further questions 315
Appendix: A nonrigorous derivation of Itô's lemma 317

Chapter 15. The Black–Scholes–Merton model 319
15.1 Lognormal property of stock prices 320
15.2 The distribution of the rate of return 321
15.3 The expected return 322
15.4 Volatility 323
15.5 The idea underlying the Black–Scholes–Merton differential equation 327
15.6 Derivation of the Black–Scholes–Merton differential equation 329
15.7 Risk-neutral valuation 332
15.8 Black–Scholes–Merton pricing formulas 333
15.9 Cumulative normal distribution function 336
15.10 Warrants and employee stock options 337
15.11 Implied volatilities 339
15.12 Dividends 341
Summary 344
Further reading 345
Practice questions 346
Further questions 348
Appendix: Proof of Black–Scholes–Merton formula using risk-neutral valuation 350

Chapter 16. Employee stock options 352
16.1 Contractual arrangements 352
16.2 Do options align the interests of shareholders and managers? 354
16.3 Accounting issues 355
16.4 Valuation 356
16.5 Backdating scandals 361
Summary 362
Further reading 362
Practice questions 362
Further questions 363

Chapter 17. Options on stock indices and currencies 365
17.1 Options on stock indices 365
17.2 Currency options 367
17.3 Options on stocks paying known dividend yields 370
17.4 Valuation of European stock index options 372
17.5 Valuation of European currency options 375
17.6 American options 376
Summary 377
Further reading 377
Practice questions 378
Further questions 380

Chapter 18. Futures options and Black's model 381
18.1 Nature of futures options 381
18.2 Reasons for the popularity of futures options 384
18.3 European spot and futures options 384
18.4 Put–call parity 385
18.5 Bounds for futures options 386

18.6 Drift of a futures prices in a risk-neutral world 387
18.7 Black's model for valuing futures options 388
18.8 Using Black's model instead of Black–Scholes–Merton 389
18.9 Valuation of futures options using binomial trees 390
18.10 American futures options vs. American spot options 392
18.11 Futures-style options 393
Summary 393
Further reading 394
Practice questions 394
Further questions 396

Chapter 19. The Greek letters 397
19.1 Illustration 397
19.2 Naked and covered positions 398
19.3 Greek letter calculation 400
19.4 Delta hedging 401
19.5 Theta 407
19.6 Gamma 409
19.7 Relationship between delta, theta, and gamma 413
19.8 Vega 414
19.9 Rho 416
19.10 The realities of hedging 417
19.11 Scenario analysis 417
19.12 Extension of formulas 419
19.13 Portfolio insurance 421
19.14 Stock market volatility 423
Summary 423
Further reading 425
Practice questions 425
Further questions 427
Appendix: Taylor series expansions and Greek letters 429

Chapter 20. Volatility smiles 430
20.1 Why the volatility smile is the same for calls and puts 430
20.2 Foreign currency options 432
20.3 Equity options 435
20.4 Alternative ways of characterizing the volatility smile 437
20.5 The volatility term structure and volatility surfaces 437
20.6 Minimum variance delta 439
20.7 The role of the model 439
20.8 When a single large jump is anticipated 440
Summary 441
Further reading 442
Practice questions 443
Further questions 444
Appendix: Determining implied risk-neutral distributions from volatility smiles 446

Chapter 21. Basic numerical procedures 449
21.1 Binomial trees 449
21.2 Using the binomial tree for options on indices, currencies, and futures contracts 457
21.3 Binomial model for a dividend-paying stock 459
21.4 Alternative procedures for constructing trees 464

21.5 Time-dependent parameters 467
21.6 Monte Carlo simulation 468
21.7 Variance reduction procedures 474
21.8 Finite difference methods 477
Summary 487
Further reading 488
Practice questions 489
Further questions 491

Chapter 22. Value at risk and expected shortfall 493
22.1 The VaR and ES measures 493
22.2 Historical simulation 496
22.3 Model-building approach 500
22.4 The linear model 503
22.5 The quadratic model 508
22.6 Monte Carlo simulation 511
22.7 Comparison of approaches 512
22.8 Back testing 512
22.9 Principal components analysis 513
Summary 516
Further reading 517
Practice questions 517
Further questions 518

Chapter 23. Estimating volatilities and correlations 520
23.1 Estimating volatility 520
23.2 The exponentially weighted moving average model 522
23.3 The GARCH (1,1) model 524
23.4 Choosing between the models 525
23.5 Maximum likelihood methods 526
23.6 Using GARCH (1,1) to forecast future volatility 531
23.7 Correlations 534
23.8 Application of EWMA to four-index example 537
Summary 539
Further reading 539
Practice questions 539
Further questions 541

Chapter 24. Credit risk 543
24.1 Credit ratings 543
24.2 Historical default probabilities 544
24.3 Recovery rates 545
24.4 Estimating default probabilities from bond yield spreads 546
24.5 Comparison of default probability estimates 549
24.6 Using equity prices to estimate default probabilities 552
24.7 Credit risk in derivatives transactions 554
24.8 Default correlation 560
24.9 Credit VaR 563
Summary 565
Further reading 565
Practice questions 566
Further questions 568

Chapter 25. Credit derivatives 569
25.1 Credit default swaps 570
25.2 Valuation of credit default swaps 573
25.3 Credit indices 577
25.4 The use of fixed coupons 578
25.5 CDS forwards and options 579
25.6 Basket credit default swaps 579
25.7 Total return swaps 579
25.8 Collateralized debt obligations 581
25.9 Role of correlation in a basket CDS and CDO 583
25.10 Valuation of a synthetic CDO 583
25.11 Alternatives to the standard market model 590
Summary 592
Further reading 592
Practice questions 593
Further questions 594

Chapter 26. Exotic options 596
26.1 Packages 596
26.2 Perpetual American call and put options 597
26.3 Nonstandard American options 598
26.4 Gap options 599
26.5 Forward start options 600
26.6 Cliquet options 600
26.7 Compound options 600
26.8 Chooser options 601
26.9 Barrier options 602
26.10 Binary options 604
26.11 Lookback options 605
26.12 Shout options 607
26.13 Asian options 608
26.14 Options to exchange one asset for another 609
26.15 Options involving several assets 610
26.16 Volatility and variance swaps 611
26.17 Static options replication 614
Summary 616
Further reading 617
Practice questions 617
Further questions 619

Chapter 27. More on models and numerical procedures 622
27.1 Alternatives to Black–Scholes–Merton 623
27.2 Stochastic volatility models 628
27.3 The IVF model 630
27.4 Convertible bonds 632
27.5 Path-dependent derivatives 634
27.6 Barrier options 637
27.7 Options on two correlated assets 640
27.8 Monte Carlo simulation and American options 642
Summary 646
Further reading 647
Practice questions 648
Further questions 650

Chapter 28. Martingales and measures 652
28.1 The market price of risk 653
28.2 Several state variables 656
28.3 Martingales 657
28.4 Alternative choices for the numeraire 658
28.5 Extension to several factors 661
28.6 Black's model revisited 662
28.7 Option to exchange one asset for another 663
28.8 Change of numeraire 664
Summary 666
Further reading 667
Practice questions 667
Further questions 668

Chapter 29. Interest rate derivatives: The standard market models 670
29.1 Bond options 670
29.2 Interest rate caps and floors 675
29.3 European swap options 681
29.4 Hedging interest rate derivatives 684
Summary 685
Further reading 686
Practice questions 686
Further questions 688

Chapter 30. Convexity, timing, and quanto adjustments 689
30.1 Convexity adjustments 689
30.2 Timing adjustments 693
30.3 Quantos 695
Summary 698
Further reading 698
Practice questions 698
Further questions 700
Appendix: Proof of the convexity adjustment formula 701

Chapter 31. Equilibrium models of the short rate 702
31.1 Background 702
31.2 One-factor models 704
31.3 Real-world vs. risk-neutral processes 709
31.4 Estimating parameters 710
31.5 More sophisticated models 711
Summary 712
Further reading 712
Practice questions 712
Further questions 713

Chapter 32. No-arbitrage models of the short rate 715
32.1 Extensions of equilibrium models 715
32.2 Options on bonds 719
32.3 Volatility structures 720
32.4 Interest rate trees 721
32.5 A general tree-building procedure 723
32.6 Calibration 732
32.7 Hedging using a one-factor model 734
Summary 735
Further reading 735

Practice questions ... 735
Further questions ... 736

Chapter 33. HJM, LMM, and multiple zero curves ... 738
33.1 The Heath, Jarrow, and Morton model ... 738
33.2 The LIBOR market model ... 741
33.3 Handling multiple zero curves ... 751
33.4 Agency mortgage-backed securities ... 752
Summary ... 754
Further reading ... 755
Practice questions ... 755
Further questions ... 756

Chapter 34. Swaps Revisited ... 757
34.1 Variations on the vanilla deal ... 757
34.2 Compounding swaps ... 759
34.3 Currency swaps ... 760
34.4 More complex swaps ... 761
34.5 Equity swaps ... 764
34.6 Swaps with embedded options ... 765
34.7 Other swaps ... 768
Summary ... 769
Further reading ... 770
Practice questions ... 770
Further questions ... 770

Chapter 35. Energy and commodity derivatives ... 772
35.1 Agricultural commodities ... 772
35.2 Metals ... 773
35.3 Energy products ... 774
35.4 Modeling commodity prices ... 776
35.5 Weather derivatives ... 782
35.6 Insurance derivatives ... 783
35.7 Pricing weather and insurance derivatives ... 784
35.8 How an energy producer can hedge risks ... 785
Summary ... 786
Further reading ... 786
Practice questions ... 787
Further question ... 788

Chapter 36. Real options ... 789
36.1 Capital investment appraisal ... 789
36.2 Extension of the risk-neutral valuation framework ... 790
36.3 Estimating the market price of risk ... 792
36.4 Application to the valuation of a business ... 793
36.5 Evaluating options in an investment opportunity ... 793
Summary ... 800
Further reading ... 800
Practice questions ... 801
Further questions ... 801

Chapter 37. Derivatives mishaps and what we can learn from them ... 803
37.1 Lessons for all users of derivatives ... 803
37.2 Lessons for financial institutions ... 807
37.3 Lessons for nonfinancial corporations ... 812

Summary 814
Further reading 814
Glossary of terms 815
DerivaGem software 838
Major exchanges trading futures and options 843
Tables for $N(x)$ 844
Credits 846
Author index 847
Subject index 851

BUSINESS SNAPSHOTS

1.1 The Lehman Bankruptcy 4
1.2 Systemic Risk 5
1.3 Hedge Funds 12
1.4 SocGen's Big Loss in 2008 18
2.1 The Unanticipated Delivery of a Futures Contract 25
2.2 Long-Term Capital Management's Big Loss 34
3.1 Hedging by Gold Mining Companies 54
3.2 Metallgesellschaft: Hedging Gone Awry 69
4.1 Orange County's Yield Curve Plays 91
4.2 Liquidity and the 2007–2009 Financial Crisis 101
5.1 Kidder Peabody's Embarrassing Mistake 112
5.2 A Systems Error? 117
5.3 The CME Nikkei 225 Futures Contract 119
5.4 Index Arbitrage in October 1987 120
6.1 Day Counts Can Be Deceptive 136
6.2 The Wild Card Play 142
6.3 Asset–Liability Management by Banks 150
7.1 Extract from Hypothetical Swap Confirmation 163
7.2 The Hammersmith and Fulham Story 176
8.1 The Basel Committee 195
10.1 Gucci Group's Large Dividend 218
10.2 Tax Planning Using Options 225
11.1 Put–Call Parity and Capital Structure 242
12.1 Losing Money with Box Spreads 261
12.2 How to Make Money from Trading Straddles 266
15.1 Mutual Fund Returns Can be Misleading 324
15.2 What Causes Volatility? 327
15.3 Warrants, Employee Stock Options, and Dilution 338
17.1 Can We Guarantee that Stocks Will Beat Bonds in the Long Run? 374
19.1 Dynamic Hedging in Practice 418
19.2 Was Portfolio Insurance to Blame for the Crash of 1987? 424
20.1 Making Money from Foreign Currency Options 434
20.2 Crashophobia 437
21.1 Calculating Pi with Monte Carlo Simulation 468
21.2 Checking Black–Scholes–Merton in Excel 471
22.1 How Bank Regulators Use VaR 494
24.1 Downgrade Triggers and AIG 558
25.1 Who Bears the Credit Risk? 570
25.2 The CDS Market 572
26.1 Is Delta Hedging Easier or More Difficult for Exotics? 615
29.1 Put–Call Parity for Caps and Floors 677
29.2 Swaptions and Bond Options 682
30.1 Siegel's Paradox 697
33.1 IOs and POs 754
34.1 Hypothetical Confirmation for Nonstandard Swap 758
34.2 Hypothetical Confirmation for Compounding Swap 759
34.3 Hypothetical Confirmation for an Equity Swap 765
34.4 Procter and Gamble's Bizarre Deal 769
36.1 Valuing Amazon.com 794
37.1 Big Losses by Financial Institutions 804
37.2 Big Losses by Nonfinancial Organizations 805

TECHNICAL NOTES

Available on the Author's Website
www-2.rotman.utoronto.ca/~hull/technicalnotes

1. Convexity Adjustments to Eurodollar Futures
2. Properties of the Lognormal Distribution
3. Warrant Valuation When Value of Equity plus Warrants Is Lognormal
4. Exact Procedure for Valuing American Calls on Stocks Paying a Single Dividend
5. Calculation of the Cumulative Probability in a Bivariate Normal Distribution
6. Differential Equation for Price of a Derivative on a Stock Paying a Known Dividend Yield
7. Differential Equation for Price of a Derivative on a Futures Price
8. Analytic Approximation for Valuing American Options
9. Generalized Tree-Building Procedure
10. The Cornish–Fisher Expansion to Estimate VaR
11. Manipulation of Credit Transition Matrices
12. Calculation of Cumulative Noncentral Chi-Square Distribution
13. Efficient Procedure for Valuing American-Style Lookback Options
14. The Hull–White Two-Factor Model
15. Valuing Options on Coupon-Bearing Bonds in a One-Factor Interest Rate Model
16. Construction of an Interest Rate Tree with Nonconstant Time Steps and Nonconstant Parameters
17. The Process for the Short Rate in an HJM Term Structure Model
18. Valuation of a Compounding Swap
19. Valuation of an Equity Swap
20. Changing the Market Price of Risk for Variables That Are Not the Prices of Traded Securities
21. Hermite Polynomials and Their Use for Integration
22. Valuation of a Variance Swap
23. The Black, Derman, Toy Model
24. Proof that Forward and Futures Prices are Equal When Interest Rates Are Constant
25. A Cash-Flow Mapping Procedure
26. A Binomial Measure of Credit Correlation
27. Calculation of Moments for Valuing Asian Options
28. Calculation of Moments for Valuing Basket Options
29. Proof of Extensions to Itô's Lemma
30. The Return of a Security Dependent on Multiple Sources of Uncertainty
31. Properties of Ho–Lee and Hull–White Interest Rate Models

Preface

It is sometimes hard for me to believe that the first edition of this book was only 330 pages and 13 chapters long! The book has grown and been adapted to keep up with the fast pace of change in derivatives markets.

Like earlier editions, the book serves several markets. It is appropriate for graduate courses in business, economics, financial mathematics, and financial engineering. It can be used on advanced undergraduate courses when students have good quantitative skills. Many practitioners who are involved in derivatives markets also find the book useful. I am delighted that the book sells equally well in the practitioner and college markets.

One of the key decisions that must be made by an author who is writing in the area of derivatives concerns the use of mathematics. If the level of mathematical sophistication is too high, the material is likely to be inaccessible to many students and practitioners. If it is too low, some important issues will inevitably be treated in a rather superficial way. I have tried to be particularly careful about the way I use mathematics in the book. Notation involving many subscripts, superscripts, or function arguments can be off-putting to a reader unfamiliar with the material and has been avoided as far as possible. Nonessential mathematical material has been either eliminated or included in the technical notes on my website and the end-of-chapter appendices. Concepts that are likely to be new to many readers have been explained carefully, and many numerical examples have been included.

Options, Futures, and Other Derivatives can be used for a first course in derivatives or for a more advanced course. There are many different ways it can be used in the classroom. Instructors teaching a first course in derivatives are likely to want to spend most classroom time on the first half of the book. Instructors teaching a more advanced course will find that many different combinations of chapters in the second half of the book can be used. I find that the material in Chapter 37 works well at the end of either an introductory or an advanced course.

What's New in the Tenth Edition?

Material has been updated and improved. OIS discounting is now used throughout the book. This makes the presentation of the material more straightforward and more theoretically appealing. The valuation of instruments such as swaps and forward rate agreements requires (a) forward rates for the rate used to calculate payments (usually LIBOR) and (b) the risk-free zero curve used for discounting (usually the OIS zero curve). The methods presented can be extended to situations where payments are dependent on any risky rate.

The changes in the tenth edition include the following:

1. A rewrite of the chapter on swaps (Chapter 7) to improve presentation and reflect changing market practices.
2. A new chapter (Chapter 9) on valuation adjustments (CVA, DVA, FVA, MVA, and KVA). Financial economists have reservations about FVA, MVA, and KVA (and these are explained), but XVAs have become such an important part of derivatives valuation that it is important to cover them.
3. Material at various points in the book on how negative interest rates can be handled in pricing models. In the no-arbitrage world that we assume when valuing derivatives, negative rates make no sense. But they are a feature of financial markets in a number of European countries and Japan and cannot be ignored.
4. A new chapter on equilibrium models of the term structure (Chapter 31). These models are important pedagogically and are widely used in long-term scenario analyses. I decided that they deserved their own chapter.
5. More details on the calculation of Greek letters and smile dynamics.
6. More discussion of the expected shortfall measure and stressed risk measures, reflecting their increasing use in regulation and risk management.
7. Coverage of the SABR model.
8. Updated material on CCPs and the regulation of OTC derivatives.
9. Improved material on martingales and measures, tailing the hedge, bootstrap methods, and convertible bonds.
10. Updating of examples to reflect current market conditions.
11. New end-of chapter problems and revisions to many old end-of-chapter problems.
12. New version of the software DerivaGem.

Software

DerivaGem 4.00 is included with this book. As before, this consists of two Excel applications: the *Options Calculator* and the *Applications Builder*. The Options Calculator consists of easy-to-use software for valuing a wide range of options. The Applications Builder consists of a number of Excel functions from which users can build their own applications. It includes a number of sample applications and enables students to explore the properties of options and numerical procedures more easily. It also allows more interesting assignments to be designed.

DerivaGem 4.00 allows a number of new models (Heston, SABR, Bachelier normal, and displaced lognormal) to be used for valuation. The software is described more fully at the end of the book. Updates to the software can be downloaded from my website:

www-2.rotman.utoronto.ca/~hull.

Slides

Several hundred PowerPoint slides can be downloaded from Pearson's Instructor Resource Center or from my website. Instructors who adopt the text are welcome to adapt the slides to meet their own needs.

Solutions Manual

End-of-chapter problems are divided into two groups: "Practice Questions" and "Further Questions." Solutions to the Practice Questions are in *Options, Futures, and Other Derivatives 10e*: *Solutions Manual* (ISBN-10: 013462999X), which is published by Pearson and can be purchased by students.

Instructors Manual

The Instructors Manual is made available online to adopting instructors by Pearson. It contains solutions to all questions (both Further Questions and Practice Questions), notes on the teaching of each chapter, test bank questions, notes on course organization, and some relevant Excel worksheets.

Technical Notes

Technical Notes are used to elaborate on points made in the text. They are referred to in the text and can be downloaded from my website:

www-2.rotman.utoronto.ca/~hull/TechnicalNotes

By not including the Technical Notes in the book, I am able to streamline the presentation of material so that it is more reader-friendly.

Acknowledgments

Many people have played a part in the development of successive editions of this book. Indeed, the list of people who have provided me with feedback on the book is now so long that it is not possible to mention everyone. I have benefited from the advice of many academics who have taught from the book and from the comments of many derivatives practitioners. I would like to thank the students on my courses at the University of Toronto who have made many suggestions on how the material can be improved. Eddie Mizzi from The Geometric Press did an excellent job editing the final manuscript and handling page composition. Emilio Barone from Luiss Guido Carli University in Rome provided many detailed comments.

Alan White, a colleague at the University of Toronto, deserves a special acknowledgment. Alan and I have been carrying out joint research and consulting in the areas of derivatives and risk management for over 30 years. During that time, we have spent many hours discussing key issues. Many of the new ideas in this book, and many of the new ways used to explain old ideas, are as much Alan's as mine. Alan has done most of the development work on the DerivaGem software.

Special thanks are due to many people at Pearson, particularly Donna Battista, Neeraj Bhalla, Nicole Suddeth, and Alison Kalil for their enthusiasm, advice and encouragement.

I welcome comments on the book from readers. My e-mail address is:

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CHAPTER 1

Introduction

In the last 40 years, derivatives have become increasingly important in finance. Futures and options are actively traded on many exchanges throughout the world. Many different types of forward contracts, swaps, options, and other derivatives are entered into by financial institutions, fund managers, and corporate treasurers in the over-the-counter market. Derivatives are added to bond issues, used in executive compensation plans, embedded in capital investment opportunities, used to transfer risks in mortgages from the original lenders to investors, and so on. We have now reached the stage where those who work in finance, and many who work outside finance, need to understand how derivatives work, how they are used, and how they are priced.

Whether you love derivatives or hate them, you cannot ignore them! The derivatives market is huge—much bigger than the stock market when measured in terms of underlying assets. The value of the assets underlying outstanding derivatives transactions is several times the world gross domestic product. As we shall see in this chapter, derivatives can be used for hedging or speculation or arbitrage. They can be used to transfer a wide range of risks in the economy from one entity to another.

A *derivative* can be defined as a financial instrument whose value depends on (or derives from) the values of other, more basic, underlying variables. Very often the variables underlying derivatives are the prices of traded assets. A stock option, for example, is a derivative whose value is dependent on the price of a stock. However, derivatives can be dependent on almost any variable, from the price of hogs to the amount of snow falling at a certain ski resort.

Since the first edition of this book was published in 1988 there have been many developments in derivatives markets. There is now active trading in credit derivatives, electricity derivatives, weather derivatives, and insurance derivatives. Many new types of interest rate, foreign exchange, and equity derivative products have been created. There have been many new ideas in risk management and risk measurement. Capital investment appraisal now often involves the evaluation of what are known as *real options*. Many new regulations have been introduced covering over-the-counter derivatives markets. The book has kept up with all these developments.

Derivatives markets have come under a great deal of criticism because of their role in the credit crisis that started in 2007. Derivative products were created from portfolios of risky mortgages in the United States using a procedure known as securitization. Many of the products that were created became worthless when house prices declined. Financial

institutions, and investors throughout the world, lost a huge amount of money and the world was plunged into the worst recession it had experienced in 75 years. Chapter 8 explains how securitization works and why such big losses occurred.

The way market participants trade and value derivatives has evolved through time. Regulatory requirements introduced since the crisis have had a huge effect on the over-the-counter market. Collateral and credit issues are now given much more attention than in the past.

Market participants have changed the proxy they use for the risk-free rate. They also now calculate a number of valuation adjustments to reflect funding costs and capital requirements, as well as credit risk. This edition has been changed to keep up to date with these developments. Chapter 9 is now devoted to a discussion of how valuation adjustments work and the extent to which they are theoretically valid.

In this opening chapter, we take a first look at derivatives markets and how they are changing. We describe forward, futures, and options markets and provide an overview of how they are used by hedgers, speculators, and arbitrageurs. Later chapters will give more details and elaborate on many of the points made here.

1.1 EXCHANGE-TRADED MARKETS

A derivatives exchange is a market where individuals trade standardized contracts that have been defined by the exchange. Derivatives exchanges have existed for a long time. The Chicago Board of Trade (CBOT) was established in 1848 to bring farmers and merchants together. Initially its main task was to standardize the quantities and qualities of the grains that were traded. Within a few years, the first futures-type contract was developed. It was known as a *to-arrive contract*. Speculators soon became interested in the contract and found trading the contract to be an attractive alternative to trading the grain itself. A rival futures exchange, the Chicago Mercantile Exchange (CME), was established in 1919. Now futures exchanges exist all over the world. (See table at the end of the book.) The CME and CBOT have merged to form the CME Group (www.cmegroup.com), which also includes the New York Mercantile Exchange (NYMEX), and the Kansas City Board of Trade (KCBT).

The Chicago Board Options Exchange (CBOE, www.cboe.com) started trading call option contracts on 16 stocks in 1973. Options had traded prior to 1973, but the CBOE succeeded in creating an orderly market with well-defined contracts. Put option contracts started trading on the exchange in 1977. The CBOE now trades options on thousands of stocks and many different stock indices. Like futures, options have proved to be very popular contracts. Many other exchanges throughout the world now trade options. (See table at the end of the book.) The underlying assets include foreign currencies and futures contracts as well as stocks and stock indices.

Once two traders have agreed on a trade, it is handled by the exchange clearing house. This stands between the two traders and manages the risks. Suppose, for example, that trader A agrees to buy 100 ounces of gold from trader B at a future time for $1,250 per ounce. The result of this trade will be that A has a contract to buy 100 ounces of gold from the clearing house at $1,250 per ounce and B has a contract to sell 100 ounces of gold to the clearing house for $1,250 per ounce. The advantage of this arrangement is that traders do not have to worry about the creditworthiness of the people they are trading with. The clearing house takes care of credit risk by requiring

each of the two traders to deposit funds (known as margin) with the clearing house to ensure that they will live up to their obligations. Margin requirements and the operation of clearing houses are discussed in more detail in Chapter 2.

Electronic Markets

Traditionally derivatives exchanges have used what is known as the *open outcry system*. This involves traders physically meeting on the floor of the exchange, shouting, and using a complicated set of hand signals to indicate the trades they would like to carry out. Exchanges have largely replaced the open outcry system by *electronic trading*. This involves traders entering their desired trades at a keyboard and a computer being used to match buyers and sellers. The open outcry system has its advocates, but, as time passes, it is becoming less and less used.

Electronic trading has led to a growth in high-frequency and algorithmic trading. This involves the use of computer programs to initiate trades, often without human intervention, and has become an important feature of derivatives markets.

1.2 OVER-THE-COUNTER MARKETS

Not all derivatives trading is on exchanges. Many trades take place in the *over-the-counter* (OTC) market. Banks, other large financial institutions, fund managers, and corporations are the main participants in OTC derivatives markets. Once an OTC trade has been agreed, the two parties can either present it to a central counterparty (CCP) or clear the trade bilaterally. A CCP is like an exchange clearing house. It stands between the two parties to the derivatives transaction so that one party does not have to bear the risk that the other party will default. When trades are cleared bilaterally, the two parties have usually signed an agreement covering all their transactions with each other. The issues covered in the agreement include the circumstances under which outstanding transactions can be terminated, how settlement amounts are calculated in the event of a termination, and how the collateral (if any) that must be posted by each side is calculated. CCPs and bilateral clearing are discussed in more detail in Chapter 2.

Large banks often act as market makers for the more commonly traded instruments. This means that they are always prepared to quote a bid price (at which they are prepared to take one side of a derivatives transaction) and an offer price (at which they are prepared to take the other side).

Prior to the credit crisis, which started in 2007 and is discussed in some detail in Chapter 8, OTC derivatives markets were largely unregulated. Following the credit crisis and the failure of Lehman Brothers (see Business Snapshot 1.1), we have seen the development of many new regulations affecting the operation of OTC markets. The main objectives of the regulations are to improve the transparency of OTC markets and reduce systemic risk (see Business Snapshot 1.2). The over-the-counter market in some respects is being forced to become more like the exchange-traded market. Three important changes are:

1. Standardized OTC derivatives between two financial institutions in the United States must, whenever possible, be traded on what are referred to a *swap execution*

Business Snapshot 1.1 The Lehman Bankruptcy

On September 15, 2008, Lehman Brothers filed for bankruptcy. This was the largest bankruptcy in U.S. history and its ramifications were felt throughout derivatives markets. Almost until the end, it seemed as though there was a good chance that Lehman would survive. A number of companies (e.g., the Korean Development Bank, Barclays Bank in the United Kingdom, and Bank of America) expressed interest in buying it, but none of these was able to close a deal. Many people thought that Lehman was "too big to fail" and that the U.S. government would have to bail it out if no purchaser could be found. This proved not to be the case.

How did this happen? It was a combination of high leverage, risky investments, and liquidity problems. Commercial banks that take deposits are subject to regulations on the amount of capital they must keep. Lehman was an investment bank and not subject to these regulations. By 2007, its leverage ratio had increased to 31:1, which means that a 3–4% decline in the value of its assets would wipe out its capital. Dick Fuld, Lehman's Chairman and Chief Executive Officer, encouraged an aggressive deal-making, risk-taking culture. He is reported to have told his executives: "Every day is a battle. You have to kill the enemy." The Chief Risk Officer at Lehman was competent, but did not have much influence and was even removed from the executive committee in 2007. The risks taken by Lehman included large positions in the instruments created from subprime mortgages, which will be described in Chapter 8. Lehman funded much of its operations with short-term debt. When there was a loss of confidence in the company, lenders refused to renew this funding, forcing it into bankruptcy.

Lehman was very active in the over-the-counter derivatives markets. It had over a million transactions outstanding with about 8,000 different counterparties. Lehman's counterparties were often required to post collateral and this collateral had in many cases been used by Lehman for various purposes. Litigation aimed at determining who owes what to whom continued for many years after the bankruptcy filing.

facilities (SEFs). These are platforms similar to exchanges where market participants can post bid and offer quotes and where market participants can trade by accepting the quotes of other market participants.

2. There is a requirement in most parts of the world that a CCP be used for most standardized derivatives transactions between financial institutions.
3. All trades must be reported to a central repository.

Market Size

Both the over-the-counter and the exchange-traded market for derivatives are huge. The number of derivatives transactions per year in OTC markets is smaller than in exchange-traded markets, but the average size of the transactions is much greater. Although the statistics that are collected for the two markets are not exactly comparable, it is clear that the volume of business in the over-the-counter market is much larger than in the exchange-traded market. The Bank for International Settlements (www.bis.org) started collecting statistics on the markets in 1998. Figure 1.1 compares (a) the estimated total