An Undergraduate Introduction To Financial Mathematics

An Undergraduate Introduction To Financial Mathematics An undergraduate introduction to financial mathematics provides students with foundational knowledge of how mathematical techniques are applied to solve problems in finance. This interdisciplinary field combines concepts from mathematics, economics, and finance to analyze and model financial markets, instruments, and risk management strategies. Whether aspiring to work in investment banking, risk assessment, or financial analysis, understanding the basics of financial mathematics is crucial for interpreting market data, valuing financial assets, and making informed decisions. --- What Is Financial Mathematics? Financial mathematics, also known as quantitative finance or mathematical finance, involves the development and application of mathematical models to understand and predict financial market behaviors. It enables professionals to value securities, assess risks, optimize investment portfolios, and develop trading strategies. Key objectives of financial mathematics include: - Valuing financial derivatives such as options and futures - Managing and hedging financial risks - Analyzing investment opportunities - Developing algorithms for automated trading --- Core Concepts in Financial Mathematics Understanding the fundamental concepts is essential for any undergraduate studying this field. Time Value of Money The principle that money available today is worth more than the same amount in the future due to its potential earning capacity. Key formulas: - Present Value (PV): $PV = \frac{FV}{(1 + r)^t}$ - Future Value (FV): $FV = PV \times (1 + r)^t$ where: - FV = future value - PV = present value - r = interest rate per period - t = number of periods Interest Rates and Discounting Interest rates influence investment returns and the valuation of cash flows. Discounting involves calculating the present value of future cash flows using an appropriate discount rate. 2 Financial Instruments Understanding basic financial instruments is key: - Bonds: debt securities with fixed interest payments - Stocks: equity ownership in a company - Derivatives: contracts whose value depends on underlying assets --- Mathematical Tools Used in Financial Mathematics A variety of mathematical techniques underpin financial modeling. Probability and Statistics Used to model uncertain market movements and assess risks. - Probability distributions (e.g., normal distribution) - Expected value and variance - Statistical inference for model calibration Calculus Essential for modeling continuous changes, especially in derivatives pricing. - Differential equations to describe asset price dynamics - Optimization techniques for portfolio management Linear Algebra Facilitates the modeling of multiple asset portfolios and risk factors. - Matrix operations for covariance and correlation matrices - Eigenvalues and eigenvectors in principal component analysis Stochastic Processes Model random processes over time, vital in option pricing models like Black-Scholes. - Brownian motion - Geometric Brownian motion --- Key Topics in Undergraduate Financial Mathematics This section covers fundamental topics often included in introductory courses. Present and Future Value Calculations Understanding how to compute the current worth of future cash flows is foundational. Valuation of Bonds and Stocks Learning to determine the fair value of securities based on expected cash flows and discount rates. 3 Introduction to

Derivative Pricing Basic concepts behind valuing options and futures, including: - European options - The payoff functions - The concept of arbitrage Risk Management and Hedging Strategies to mitigate financial risk, such as: - Diversification - Use of derivatives like options and swaps The Black-Scholes Model A mathematical model for pricing European options, which assumes: - Log-normal distribution of asset prices - No arbitrage opportunities - Constant volatility and interest rates Black-Scholes formula for a call option: \[C = S_0 N(d_1) - K e^{-rT} N(d_2) \] where: - \(S_0\) = current stock price - \(K\) = strike price - \(T\) = time to expiration - \(r\) = risk-free interest rate - \(N(\cdot)\) = cumulative distribution function of the standard normal distribution - \(d_1, d_2\) are calculated variables based on inputs --- Applications of Financial Mathematics Financial mathematics plays a vital role across various sectors within finance. Asset Pricing and Valuation Determining the fair value of stocks, bonds, and derivatives based on market data and models. Risk Management Quantitative methods assess potential losses and develop hedging strategies to mitigate market, credit, or operational risks. Portfolio Optimization Using mathematical algorithms to maximize returns for a given level of risk, often employing techniques like mean-variance optimization. Algorithmic Trading Designing automated trading systems based on mathematical models to exploit market inefficiencies. --- 4 Challenges and Limitations While financial mathematics offers powerful tools, practitioners must be aware of inherent limitations: - Assumptions in models (e.g., constant volatility) may not hold in real markets - Market anomalies and behavioral factors often defy model predictions - Data quality and model calibration are critical for accuracy - Sudden market shocks can render models ineffective Understanding these limitations is essential for responsible application. --- Getting Started in Financial Mathematics as an Undergraduate Students interested in this field should focus on: - Building a strong foundation in calculus, probability, and statistics - Gaining knowledge of financial markets and instruments - Learning programming languages such as Python, R, or MATLAB for modeling - Engaging with coursework, internships, or research projects related to quantitative finance Many universities offer specialized courses or electives in financial mathematics, often integrated with practical case studies. --- Conclusion An undergraduate introduction to financial mathematics equips students with the essential tools to analyze and interpret financial data, value securities, and manage risks. By mastering core concepts like time value of money, derivative pricing, and stochastic processes, students lay the groundwork for advanced study or careers in finance, investment analysis, and risk management. As markets continue to evolve with increasing complexity, the role of mathematical models becomes ever more vital, making this interdisciplinary field both challenging and rewarding for aspiring financial professionals. -- - Keywords: financial mathematics, undergraduate finance, derivative pricing, risk management, Black-Scholes, portfolio optimization, stochastic processes, quantitative finance QuestionAnswer What are the main topics covered in an undergraduate introduction to financial mathematics? Typically, it covers time value of money, interest rates, present and future value calculations, basic derivatives pricing, and an introduction to financial instruments like bonds and stocks. How does the concept of the time value of money apply in financial mathematics? The time value of money reflects that a sum of money today is worth more than the same sum in the future due to its potential earning capacity, which is fundamental for valuing investments and loans. What is the significance of the Black-Scholes model in financial mathematics for undergraduates? The Black-Scholes model provides a mathematical framework for pricing European options, introducing students to stochastic processes and differential equations in finance. 5 Which mathematical tools are essential for studying financial mathematics at the undergraduate level? Essential tools include calculus, probability theory, differential equations, and basic linear

algebra, which help in modeling and analyzing financial instruments. How are bonds and interest rates modeled in introductory financial mathematics? Bonds are modeled using present value calculations, while interest rates are often represented through models like simple interest, compound interest, or more advanced stochastic models for variable rates. What role does stochastic calculus play in financial mathematics? Stochastic calculus enables modeling of random processes like stock prices and interest rates, which are crucial for pricing derivatives and managing financial risk. Why is understanding risk and return important in financial mathematics? Understanding risk and return helps in making informed investment decisions, assessing the value of financial assets, and constructing optimal portfolios. What are some common assumptions made in basic financial mathematics models? Common assumptions include market efficiency, no arbitrage opportunities, constant interest rates, and the ability to borrow or lend at a risk-free rate, which simplify modeling but may not reflect real markets. An Undergraduate Introduction to Financial Mathematics: Unlocking the Secrets of Modern Finance Financial mathematics is a fascinating and essential field that combines the principles of mathematics, economics, and finance to understand, analyze, and predict financial markets and instruments. For undergraduates venturing into this domain, it offers a powerful toolkit for making informed investment decisions, managing risk, and understanding the underlying mechanics of the financial world. In this guide, we will explore the fundamental concepts, key models, and practical applications of financial mathematics, providing a comprehensive introduction suitable for those beginning their journey in this dynamic discipline. --- What Is Financial Mathematics? Financial mathematics, also known as quantitative finance or mathematical finance, involves applying mathematical methods to solve problems related to finance. It encompasses a broad range of topics including pricing derivatives, assessing risk, portfolio optimization, and understanding market behaviors. The primary goal is to develop models that accurately represent financial markets and enable practitioners to make optimal decisions. Why Study Financial Mathematics? - Career Opportunities: Roles in investment banks, hedge funds, asset management, risk management, and financial consulting. - Practical Skills: Quantitative analysis, probabilistic reasoning, and computational techniques. - Interdisciplinary Nature: Combines mathematics, economics, statistics, and computer science. - Impact: Helps in understanding and mitigating financial risks, designing investment strategies, and creating innovative financial products. --- An Undergraduate Introduction To Financial Mathematics 6 Fundamental Concepts in Financial Mathematics Before diving into specific models, it's essential to grasp some core ideas that underpin the field. Time Value of Money (TVM) At the heart of financial mathematics lies the principle that money today is worth more than the same amount in the future due to potential earning capacity. - Present Value (PV): Value of a future sum discounted to today. - Future Value (FV): Value of an investment after accruing interest over time. - Interest Rates: The rate at which money grows over time, often expressed as annual percentage rates (APR). Risk and Return Understanding the trade-off between risk and expected return is fundamental. - Expected Return: The average return an investor anticipates. - Risk: Variability or uncertainty in returns, often measured by variance or standard deviation. - Risk Premium: Additional return expected for taking on extra risk. Probabilistic Models Financial models often rely on probability theory to account for uncertainty. - Random Variables: Outcomes such as asset prices or returns. - Probability Distributions: Models like the normal distribution, log-normal, or binomial, used to describe possible outcomes. --- Key Models and Techniques The Binomial Model One of the simplest models for option pricing, the binomial model discretizes the possible paths an asset’s price can take over time. How it works: - Assumes that at each step, the asset price can go up or down by certain factors. - Builds

a binomial tree to model potential future prices. - Uses risk-neutral valuation to price derivatives. Advantages: - Intuitive and easy to implement. - Suitable for teaching fundamental concepts of option pricing. The Black-Scholes Model Perhaps the most famous model in financial mathematics, the Black-Scholes model provides a closed-form solution for European option prices. Key assumptions: - The stock price follows a geometric Brownian motion with constant volatility. - No arbitrage opportunities. - Markets are frictionless (no transaction costs or taxes). - The risk-free rate is constant. Black- Scholes formula: \[C = S_0 N(d_1) - K e^{-rT} N(d_2) \] where: - \(C \) = call option price - \(S_0 \) = current stock price - \(K \) = strike price - \(T \) = time to maturity - \(r \) = risk-free interest rate - \(N(\cdot) \) = cumulative distribution function of the standard normal distribution - \(d_1 \) and \(d_2 \) are specific functions of the parameters involving volatility and other variables. Significance: - Provides a foundation for modern derivative pricing. - Introduces concepts like hedging and risk-neutral valuation. Stochastic Processes and Ito Calculus For more advanced modeling, stochastic calculus is employed to describe the random evolution of asset prices. - Brownian Motion (Wiener Process): A continuous-time stochastic process with independent, normally distributed increments. - Ito's Lemma: A fundamental tool for manipulating stochastic differential equations (SDEs). Applications: - Modeling complex financial derivatives. - Deriving the Black-Scholes equation. - Analyzing market dynamics under randomness. --- Practical Applications of Financial Mathematics Derivative Pricing Financial mathematics provides the tools to determine the fair value of options, futures, and other derivatives, which are contracts whose value depends on underlying assets. Portfolio Optimization Using models An Undergraduate Introduction To Financial Mathematics 7 like Markowitz's mean-variance framework, investors can construct portfolios that maximize expected return for a given level of risk. Risk Management Quantitative models help identify, measure, and mitigate risks such as market risk, credit risk, and operational risk. Algorithmic Trading Mathematical models underpin automated trading strategies that execute trades at high speed based on quantitative signals. --- Challenges and Limitations While financial mathematics offers powerful insights, it is not without limitations: - Model Assumptions: Many models assume markets are efficient and frictionless, which isn't always true. - Parameter Estimation: Accurate input parameters (like volatility) are crucial but often difficult to estimate. - Market Anomalies: Unexpected events or behavioral factors can cause models to fail. - Regulatory and Ethical Considerations: Financial models must be applied responsibly, considering legal and ethical standards. --- Getting Started in Financial Mathematics For undergraduates interested in exploring this field: 1. Build a Strong Mathematical Foundation: Focus on calculus, linear algebra, probability, and statistics. 2. Learn Programming Skills: Familiarity with Python, R, or MATLAB aids in implementing models. 3. Study Financial Theory: Understand how markets work and basic economic principles. 4. Engage with Practical Projects: Analyze real market data, simulate models, or participate in competitions. 5. Pursue Specialized Courses: Look for electives in derivatives, stochastic processes, and econometrics. --- Conclusion An undergraduate introduction to financial mathematics opens the door to understanding the quantitative backbone of modern finance. From the simple binomial model to the sophisticated machinery of stochastic calculus, this field combines theoretical rigor with practical relevance. Whether you aspire to be a financial analyst, risk manager, or quantitative researcher, mastering these concepts will equip you with the skills to navigate and contribute to the complex world of finance. By developing a solid grounding in mathematical principles and their applications, students can not only enhance their analytical capabilities but also play a vital role in shaping innovative financial solutions and strategies in the ever-evolving landscape of global markets. financial mathematics, undergraduate finance, financial modeling,

time value of money, risk management, investment analysis, financial derivatives, quantitative finance, probability theory, actuarial mathematics

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this textbook provides an introduction to financial mathematics and financial engineering for undergraduate students who have completed a three or four semester sequence of calculus courses it introduces the theory of interest random variables and probability stochastic processes arbitrage option pricing hedging and portfolio optimization the student progresses from knowing only elementary calculus to understanding the derivation and solution of the black scholes partial differential equation and its solutions this is one of the few books on the subject of financial mathematics which is accessible to undergraduates having only a thorough grounding in elementary calculus it explains the subject matter without hand waving arguments and includes numerous examples every chapter concludes with a set of exercises which test the chapter s concepts and fill in details of derivations publisher s description

this textbook provides an introduction to financial mathematics and financial engineering for undergraduate students who have completed a three or four semester

sequence of calculus courses it introduces the theory of interest discrete and continuous random variables and probability stochastic processes linear programming the fundamental theorem of finance option pricing hedging and portfolio optimization the reader progresses from a solid grounding in multi variable calculus through a derivation of the black scholes equation its solution properties and applications

the book has been tested and refined through years of classroom teaching experience with an abundance of examples problems and fully worked out solutions the text introduces the financial theory and relevant mathematical methods in a mathematically rigorous yet engaging way this textbook provides complete coverage of continuous time financial models that form the cornerstones of financial derivative pricing theory unlike similar texts in the field this one presents multiple problem solving approaches linking related comprehensive techniques for pricing different types of financial derivatives key features in depth coverage of continuous time theory and methodology numerous fully worked out examples and exercises in every chapter mathematically rigorous and consistent yet bridging various basic and more advanced concepts judicious balance of financial theory and mathematical methods guide to material this revision contains almost 150 pages worth of new material in all chapters a appendix on probability theory an expanded set of solved problems and additional exercises answers to all exercises this book is a comprehensive self contained and unified treatment of the main theory and application of mathematical methods behind modern day financial mathematics the text complements financial mathematics a comprehensive treatment in discrete time by the same authors also published by crc press

this textbook contains the fundamentals for an undergraduate course in mathematical finance aimed primarily at students of mathematics assuming only a basic knowledge of probability and calculus the material is presented in a mathematically rigorous and complete way the book covers the time value of money including the time structure of interest rates bonds and stock valuation derivative securities futures options modelling in discrete time pricing and hedging and many other core topics with numerous examples problems and exercises this book is ideally suited for independent study

this book s primary objective is to educate aspiring finance professionals about mathematics and computation in the context of financial derivatives the authors offer a balance of traditional coverage and technology to fill the void between highly mathematical books and broad finance books the focus of this book is twofold to partner mathematics with corresponding intuition rather than diving so deeply into the mathematics that the material is inaccessible to many readers to build reader intuition understanding and confidence through three types of computer applications that help the reader understand the mathematics of the models unlike many books on financial derivatives requiring stochastic calculus this book presents the fundamental theories based on only undergraduate probability knowledge a key feature of this book is its focus on applying models in three programming languages r mathematica and excel each of the three approaches offers unique advantages the computer applications are carefully introduced and require little prior programming background the financial derivative models that are included in this book are virtually identical to those covered in the top financial professional certificate programs in finance the overlap of financial models between these programs and this book is broad and deep

financial mathematics from discrete to continuous time is a study of the mathematical ideas and techniques that are important to the two main arms of the area of financial mathematics portfolio optimization and derivative valuation the text is authored for courses taken by advanced undergraduates mba or other students in quantitative finance programs the approach will be mathematically correct but informal sometimes omitting proofs of the more difficult results and stressing practical results and interpretation the text will not be dependent on any particular technology but it will be laced with examples requiring the numerical and graphical power of the machine the text illustrates simulation techniques to stand in for analytical techniques when the latter are impractical there will be an electronic version of the text that integrates mathematica functionality into the development making full use of the computational and simulation tools that this program provides prerequisites are good courses in mathematical probability acquaintance with statistical estimation and a grounding in matrix algebra the highlights of the text are a thorough presentation of the problem of portfolio optimization leading in a natural way to the capital market theory dynamic programming and the optimal portfolio selection consumption problem through time an intuitive approach to brownian motion and stochastic integral models for continuous time problems the black scholes equation for simple european option values derived in several different ways a chapter on several types of exotic options material on the management of risk in several contexts

the second edition of this successful and widely recognized textbook again focuses on discrete topics the author recognizes two distinct paths of study and careers of actuarial science and financial engineering this text can be very useful as a common core for both therefore there is substantial material in introduction to financial mathematics second edition on the theory of interest the first half of the book as well as the probabilistic background necessary for the study of portfolio optimization and derivative valuation the second half a course in multivariable calculus is not required the material in the first two chapters should go a long way toward helping students prepare for the financial mathematics fm actuarial exam also the discrete material will reveal how beneficial it is for the students to know more about loans in their personal financial lives the notable changes and updates to this edition are itemized in the preface but overall the presentation has been made more efficient one example is the chapter on discrete probability which is rather unique in its emphasis on giving the deterministic problems studied earlier a probabilistic context the section on markov chains which is not essential to the development has been scaled down sample spaces and probability measures random variables and distributions expectation conditional probability independence and estimation all follow optimal portfolio selection coverage is reorganized and the section on the practicalities of stock transactions has been revised market portfolio and capital market theory coverage is expanded new sections on swaps and value at risk have been added this book like the first edition was written so that the print edition could stand alone at times we simplify complicated algebraic expressions or solve systems of linear equations or numerically solve non linear equations also some attention is given to the use of computer simulation to approximate solutions to problems

anyone with an interest in learning about the mathematical modeling of prices of financial derivatives such as bonds futures and options can start with this book whereby the only mathematical prerequisite is multivariable calculus the necessary theory of interest statistical stochastic and differential equations are developed in their respective chapters with the goal of making this introductory text as self contained as possible in this edition the chapters on hedging portfolios and extensions of the

black scholes model have been expanded the chapter on optimizing portfolios has been completely re written to focus on the development of the capital asset pricing model the binomial model due to cox ross rubinstein has been enlarged into a standalone chapter illustrating the wide ranging utility of the binomial model for numerically estimating option prices there is a completely new chapter on the pricing of exotic options the appendix now features linear algebra with sufficient background material to support a more rigorous development of the arbitrage theorem the new edition has more than doubled the number of exercises compared to the previous edition and now contains over 700 exercises thus students completing the book will gain a deeper understanding of the development of modern financial mathematics

as with the first edition mathematics for finance an introduction to financial engineering combines financial motivation with mathematical style assuming only basic knowledge of probability and calculus it presents three major areas of mathematical finance namely option pricing based on the no arbitrage principle in discrete and continuous time setting markowitz portfolio optimisation and capital asset pricing model and basic stochastic interest rate models in discrete setting from the reviews of the first edition this text is an excellent introduction to mathematical finance armed with a knowledge of basic calculus and probability a student can use this book to learn about derivatives interest rates and their term structure and portfolio management zentralblatt math given these basic tools it is surprising how high a level of sophistication the authors achieve covering such topics as arbitrage free valuation binomial trees and risk neutral valuation riskbook com the reviewer can only congratulate the authors with successful completion of a difficult task of writing a useful textbook on a traditionally hard topic k borovkov the australian mathematical society gazette vol 31 4 2004

this book is an elementary introduction to the basic concepts of financial mathematics with a central focus on discrete models and an aim to demonstrate simple but widely used financial derivatives for managing market risks only a basic knowledge of probability real analysis ordinary differential equations linear algebra and some common sense are required to understand the concepts considered in this book financial mathematics is an application of advanced mathematical and statistical methods to financial management and markets with a main objective of quantifying and hedging risks since the book aims to present the basics of financial mathematics to the reader only essential elements of probability and stochastic analysis are given to explain ideas concerning derivative pricing and hedging to keep the reader intrigued and motivated the book has a sandwich structure probability and stochastics are given in situ where mathematics can be readily illustrated by application to finance the first part of the book introduces one of the main principles in finance no arbitrage pricing it also introduces main financial instruments such as forward and futures contracts bonds and swaps and options the second part deals with pricing and hedging of european and american type options in the discrete time setting in addition the concept of complete and incomplete markets is discussed elementary probability is briefly revised and discrete time discrete space stochastic processes used in financial modelling are considered the third part introduces the wiener process ito integrals and stochastic differential equations but its main focus is the famous black scholes formula for pricing european options some guidance for further study within this exciting and rapidly changing field is given in the concluding chapter there

are approximately 100 exercises interspersed throughout the book and solutions for most problems are provided in the appendices

mathematics for finance an introduction to financial engineering combines financial motivation with mathematical style assuming only basic knowledge of probability and calculus it presents three major areas of mathematical finance namely option pricing based on the no arbitrage principle in discrete and continuous time setting markowitz portfolio optimisation and capital asset pricing model and basic stochastic interest rate models in discrete setting

this book follows a conversational approach in five dozen stories that provide an insight into the colorful world of financial mathematics and financial markets in a relaxed accessible and entertaining form the authors present various topics such as returns real interest rates present values arbitrage replication options swaps the black scholes formula and many more the readers will learn how to discover analyze and deal with the many financial mathematical decisions the daily routine constantly demands the book covers a wide field in terms of scope and thematic diversity numerous stories are inspired by the fields of deterministic financial mathematics option valuation portfolio optimization and actuarial mathematics the book also contains a collection of basic concepts and formulas of financial mathematics and of probability theory thus also readers new to the subject will be provided with all the necessary information to verify the calculations

introduction to financial mathematics option valuation second edition is a well rounded primer to the mathematics and models used in the valuation of financial derivatives the book consists of fifteen chapters the first ten of which develop option valuation techniques in discrete time the last five describing the theory in continuous time the first half of the textbook develops basic finance and probability the author then treats the binomial model as the primary example of discrete time option valuation the final part of the textbook examines the black scholes model the book is written to provide a straightforward account of the principles of option pricing and examines these principles in detail using standard discrete and stochastic calculus models additionally the second edition has new exercises and examples and includes many tables and graphs generated by over 30 ms excel vba modules available on the author s webpage home gwu edu hdj

intro title page full title page copyright dedication preface contents chapter 1 chapter 2 chapter 3 chapter 4 chapter 5 chapter 6 chapter 7 chapter 8 chapter 9 chapter 10 chapter 11 chapter 12 chapter 13 chapter 14 chapter 15 references index

this second edition presents an applied approach to financial mathematics and provides an overview of existing and original material sophisticated theories are presented systematically in a user friendly style which promotes a powerful combination of mathematical rigor and mathematica programming three kinds of solution methods are emphasized symbolic numerical and monte carlo this new comprehensive study guide presents several additional financial problems that can be directly applied in the field i e integral pde dupire equations inverse problems 3 d numerical pricing equations obstacle problems optimal portfolio problem for momentum markets the book is

intended for instructors and graduate students interested in financial mathematics as well as mathematically inclined investors and traders who rely on cash stocks and stock options on a regular basis

this book s primary objective is to educate aspiring finance professionals about mathematics and computation in the context of financial derivatives the authors offer a balance of traditional coverage and technology to fill the void between highly mathematical books and broad finance books the focus of this book is twofold to partner mathematics with corresponding intuition rather than diving so deeply into the mathematics that the material is inaccessible to many readers to build reader intuition understanding and confidence through three types of computer applications that help the reader understand the mathematics of the models unlike many books on financial derivatives requiring stochastic calculus this book presents the fundamental theories based on only undergraduate probability knowledge a key feature of this book is its focus on applying models in three programming languages r mathematica and excel each of the three approaches offers unique advantages the computer applications are carefully introduced and require little prior programming background the financial derivative models that are included in this book are virtually identical to those covered in the top financial professional certificate programs in finance the overlap of financial models between these programs and this book is broad and deep

swaps futures options structured instruments a wide range of derivative products is traded in today s financial markets analyzing pricing and managing such products often requires fairly sophisticated quantitative tools and methods this book serves as an introduction to financial mathematics with special emphasis on aspects relevant in practice in addition to numerous illustrative examples algorithmic implementations are demonstrated using mathematica and the software package unrisk available for both students and teachers the content is organized in 15 chapters that can be treated as independent modules in particular the exposition is tailored for classroom use in a bachelor or master program course as well as for practitioners who wish to further strengthen their quantitative background

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Introduction

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