CERTIFICATE IN QUANTITATIVE FINANCE

CQF

Certificate in Quantitative Finance

Learning Pathway

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CQF

Welcome to the CQF program

This booklet is designed to guide you through the program content of the CQF. It also includes the core text book reading list, indicating the chapters appropriate for each module.

The examined part of the CQF program comprises six modules. Each module covers a different aspect of quantitative finance and consists of lectures and discussions. The preparatory reading listed against each module gives you a good introduction to the topics discussed in lectures. The further reading allows you to delve deeper into each topic and are recommended but not required as part of the program.

Our Lifelong Learning library encompasses over 900 hours of lectures on every conceivable finance subject. The Lifelong Learning lectures listed support the core lectures. As the content is ever expanding, it is advisable to check the library regularly.

Module 1

Building Blocks of Quant Finance

This module introduces the rules of applied Itô calculus as a modeling framework. We build tools in both stochastic calculus and martingale theory and look at simple stochastic differential equations and their associated Fokker-Planck and Kolmogorov equations.

- **The Random Nature of Prices:** Examination of data, unpredictability, the need for probabilistic models, drift and volatility.
- **Probability Preliminaries:** Review of discrete and continuous random variables, transition density functions, moments and important distributions, the Central Limit Theorem.
- **Fokker-Planck and Kolmogorov Equations:** similarity solutions.
- **Applied Itô Calculus:** Discrete-time random walks, continuous Wiener processes via rescaling and passing to the limit, quadratic variation, Itô integrals and Itô's lemma.
- Simulating and manipulating stochastic differential equations.
- **The Binomial Model:** Up and down moves, delta hedging and self-financing replication, no arbitrage, a pricing model and risk-neutral probabilities.
- **Discrete Martingales:** Probabilistic universe, sample space, filtration and probability measures, conditional expectations, change of measure.
- **Continuous Martingales:** Discrete and continuous time martingales, Markov vs Martingale, Ito integrals and martingales, stochastic processes as martingale and tools of the trade.
- **Discrete Time Finance:** Binomial Model, risk-neutrality, replication, risk-neutral probabilities - the connection between expectations and option pricing.

Preparatory reading:

- Paul Wilmott, *Paul Wilmott Introduces Quantitative Finance*, second edition, 2007, Wiley (Chapters 3,4,5,7)

Further reading:

- James D. Hamilton, *Time Series Analysis*, 1994, Princeton University Press
- John A. Rice, *Mathematical Statistics and Data Analysis*, 1988, Wadsworth & Brooks/Cole **Available at Forum Library (519.5 RIC)**
- Salih N. Neftci, *An Introduction to the Mathematics of Financial Derivatives*, 1996, Academic Press (General reference)

Lifelong Learning lectures:

(Available to Full program and Level II delegates)

- Linear Algebra - Riaz Ahmad
- Stochastic Calculus - Riaz Ahmad
- Differential Equations - Riaz Ahmad
- Methods for Quant Finance I, II - Riaz Ahmad
- Martingales - Riaz Ahmad

Module 2

Quantitative Risk and Return

This module deals with the classical portfolio theory of Markowitz, the capital asset pricing model and more recent developments of these theories. We investigate risk and reward, looking at risk management metrics such as VaR.

- **Modern Portfolio Theory:** Expected returns, variances and covariances, benefits of diversification, the opportunity set and the efficient frontier, the Sharpe ratio, utility functions and the Black-Litterman Model.
- **Capital Asset Pricing Model:** Single-index model, beta, diversification, optimal portfolios, the multi-index model.
- **Portfolio Optimization:** Formulation, implementation and use of calculus to solve constrained optimization.
- **Risk Regulation and Basel III:** Definition of capital, evolution of Basel, Basel III and market risk, key provisions
- **Collateral and Margins:** Expected Exposure (EE), types of collateral, calculation initial and variation margins, minimum transfer amount (MTA).
- **Value at Risk:** Profit and loss for simple portfolios, tails of distributions, Monte Carlo simulations and historical simulations, stress testing and worst-case scenarios.
- **Liquidity Asset Liability Management:** Gap analysis, liabilities and contingencies, the role of derivatives and non-derivatives in liquidity, Liquidity Coverage Ratio (LCR), Net Stable Funding Rate (NSFR).
- **Volatility Cluster:** Concept and evidence.
- **Properties of Daily and High-Frequency Asset Returns:** Average values, standard deviations, five-minute returns contrasted with daily returns, intraday volatility patterns.
- **Volatility Models:** The ARCH framework, why ARCH models are popular, the GARCH model, ARCH models, asymmetric ARCH models and econometric methods.

Preparatory reading:

- Paul Wilmott, *Paul Wilmott Introduces Quantitative Finance*, second edition, 2007, Wiley (Chapters 1, 2, 3, 20-22)
- Stephen J. Taylor, *Asset Price Dynamics, Volatility and Predication*, 2007, Princeton University Press (Chapters 2, 4, 9-10, 12)

Further reading:

- Edwin J. Elton & Martin J. Gruber, *Modern Portfolio Theory and Investment Analysis*, 1995, Wiley
- Robert C. Merton, *Continuous Time Finance*, 1992, Blackwell
- Nassim Taleb, *Dynamic Hedging*, 1996, Wiley
- David G. Luenberger, *Investment Science*, June 1997, Oxford University Press (Chapters 6 & 7)
- Jonathon E. Ingersoll, *Theory of Financial Decision Making*, 1987, Rowman & Littlefield (Chapter 4)
- Salih .N. Neftci, *An Introduction to the Mathematics of Financial Derivatives*, 1996, Academic Press (general reference)
- Ruey S. Tsay, *Analysis of Financial Time Series*, third edition, 2010, Wiley
- Attilio Meucci, *Risk and Asset Allocation,* 2009, Springer Finance
- Edwin J. Elton, Martin J. Gruber, Stephen J. Brown, William N.. Goetzmann, *Modern Portfolio Theory and Investment*, ninth edition, 2010, Wiley

Lifelong Learning lectures:

(Available to Full program and Level II delegates)

- Fundamentals of Optimization - Riaz Ahmad
- Investment Lessons from Blackjack and Gambling - Paul Wilmott
- Symmetric Downside Sharpe Ratio - William Ziemba
- Beyond Black-Litterman: Views on Generic Markets - Attilio Meucci
- Financial Modeling using Garch Processes - Kyriakos Chourdakis

Module 3

Equities and Currencies

The Black-Scholes theory, built on the principles of delta hedging and no arbitrage, has been very successful and fruitful as a theoretical model and in practice. This module explains the theory and results using different kinds of mathematics to make the delegate familiar with techniques in current use.

- **The Black-Scholes Model:** A stochastic differential equation for an asset price, the delta-hedged portfolio and self-financing replication, no arbitrage, the pricing partial differential equation and simple solutions.
- **Martingales:** The probabilistic mathematics underlying derivatives theory, Girsanov, change of measure and Feynman-Kac.
- **Early Exercise:** American options, elimination of arbitrage, modifying the binomial method, gradient conditions, formulation as a free-boundary problem.
- **The Greeks:** delta, gamma, theta, vega and rho and their uses in hedging.
- **Numerical Analysis:** Monte Carlo simulation and the explicit finite-difference method.
- **Further Numerical Analysis:** Crank-Nicolson, and Douglas multi-time level methods, convergence, accuracy and stability.
- **Exotic Options:** OTC contracts and their mathematical analysis.
- **Derivatives Market Practice:** Examination of common practices and historical perspective of option pricing.
- **Advanced Volatility Modeling:** Implied vs actual, local volatility surfaces, non-linear pricing equations.

Preparatory reading:

- Paul Wilmott, *Paul Wilmott Introduces Quantitative Finance*, second edition, 2007, Wiley (Chapters 6, 8, 27-30)
- Paul Wilmott, *Paul Wilmott on Quantitative Finance*, second edition, 2006, Wiley (Chapters 14, 22-29, 37, 45-53, 57, 76-83)
- Espen G. Haug, *Derivatives: Models on Models*, 2007, Wiley (Chapter 1 & 2, and on the CD Know Your Weapon 1 & 2)

Further reading:

- Nassim Taleb, *Dynamic Hedging*, 1996, Wiley
- John C. Hull, Options, *Futures and Other Derivatives*, fifth edition, 2002, Prentice-Hall
- K.W. Morton and D.F. Mayers, *Numerical Solution of Partial Differential Equations: An Introduction*, 1994, Cambridge University Press
- Gordon .D. Smith, *Numerical Solution of Partial Differential Equations*, 1985, Oxford University Press
- Martin Baxter and Andrew Rennie, *Financial Calculus: An Introduction to Derivative Pricing*, 2001, Cambridge University Press
- Steven E. Shreve, *Stochastic Calculus for Finance II: Continuous – Time Models v.2*, 2000, Springer Finance
- Richard L. Burden and Douglas J. Faires, *Numerical Analysis*, tenth edition, 2016, Cengage Learning

Lifelong Learning lectures:

(Available to Full program and Level II delegates)

- Black-Scholes World, Mathematical Methods and Introduction to Numerical Methods - Riaz Ahmad
- Infinite Variance - Nassim Nicholas Taleb
- Introduction to Volatility Trading and Variance Swaps - Sebastien Bossu
- Advanced Equity Models: Pricing, Calibration and Monte Carlo Simulation - Wim Schoutens
- Discrete Hedging and Transaction Costs - Paul Wilmott
- Ten Ways to Derive Black-Scholes - Paul Wilmott
- Volatility Arbitrage and How to Hedge - Paul Wilmott

Module 4

Data Science and Machine Learning I

This module will introduce the latest techniques used for machine learning in finance. Starting with a comprehensive overview of the topic, the essential mathematical tools followed by a deep dive into the topic of supervised learning , including regression methods, k-Nearest neighbors, Support Vector Machines, Ensemble methods and many more.

- **Introduction to Machine Learning:** What is Mathematical Modeling, Classic Tools, Principal Techniques, Principal techniques for Machine Learning, Supervised & Unsupervised Learning, Reinforcement Learning.
- **Maths Toolbox:** Maximum Likelihood Estimation, Cost/Loss Function, Gradient Descent, Stochastic Gradient Descent, Bias & Variance, Lagrange Multipliers, Principal Component Analysis.
- **Supervised Learning I:** Linear Regression, Penalized Regression: Lasso, Ridge & Elastic Net, Logistic, Softmax Regression, Decision Trees, Ensemble Models -Bagging & Boosting.
- **Logistic Regression, Support Vector Machines, Cluster Analysis:** BIRCH, hierarchical, K-mean, Expectation maximization, DBSCAN, OPTICS and mean shift Kalman filtering.
- **Machine Learning Lab:** Supervised Learning Implementation, Python - Scikit Learn; Support Vector Machines.

Further Reading:

- Trevor Hastie et al., *The Elements of Statistical Learning: Data Mining, Inference, and Prediction, 2009* (2nd edition), Springer
- Martin Odersky et al., *Programming in Scala: Updated for Scala 2.12*, 2016 (3rd edition), Artima Press
- Macros Lopez de Prado, *Advances in Financial Machine Learning*, 2018, Wiley
- Christopher Bishop, *Pattern Recognition and Machine Learning*, 2006, Springer
- Max Kuhn and Kjell Johnson, *Applied Predictive Analytics*, 2013, Springer

Lifelong Learning Lectures:

(Available to Full program and Level II delegates)

- Machine Learning for Hedge Fund Selection - Claus Huber
- FinTech and the ML/AI/NLP Revolution - Sanjiv Das
- New Sentiment Everywhere - Peter Hafez

Module 5

Data Science and Machine Learning II

In this module we will explore several more methods used for machine learning in finance. Starting with unsupervised learning, Deep learning and Neural networks, we will move into natural language processing and reinforcement learning. You will study the theoretical framework, analyze practical case studies exploring how these techniques are used within finance.

- **Machine Learning & Predictive Analytics:** Regression, regression in high dimensions, support vector machines, dimension reduction: principal component analysis (PCA), kernel PCA, non-negative matrix decomposition.
- **Unsupervised Learning I:** K Means Clustering; Self Organizing Maps; Strengths & Weakness of HAC and SOM.
- **Unsupervised Learning II:** t-SNE; UMAP; Autoencoders.
- **Deep Learning & Neural Networks:** Structural Building Blocks; Forward & Back Propagation; Multi Output Perceptron; Building Neural Networks.
- **Neural Network Architectures:** Feedforward, Recurrent, Long Short Term Memory, Convolutional, Generative Adversarial.
- **Natural Language Processing:** Pre-processing; Word Vectorizations, Word2Vec; Deep Learning & NLP Tools.
- **Reinforcement Learning:** Multi-armed Bandit; Exploration Strategies; Risk Sensitivity.
- **AI Based Algo Trading Strategies Using Python:** Financial data analysis with Python and pandas, application of classification algorithms, vectorized backtesting, risk analysis for algo trading strategies.

Further Reading:

- William McKinney, *Python for Data Analysis*, 2013 O'Reilly
- Foster Provost and Tom Fawcett, *Data Science for Business*, 2013, O'Reilly
- Gareth James et al., *An Introduction to Statistical Learning*, 2013, Springer
- Yves Hilipisch, *Python for Finance*, 2014, (2nd edition), O'Reilly

Lifelong Learning Lectures:

(Available to Full program and Level II delegates)

- Reinforcement Learning - Thijs van den Berg
- Deep Learning Introduction - Sanjiv Das
- Deep Learning for Natural Language Processing - Nishant Chandra

Module 6

Fixed Income and Credit

In this module we will review the multitude of interest models used within the industry, focusing on the implementation and limitations of each model. You will learn about credit and how credit risk models are used in quant finance, including structural, reduced form as well as copula models.

- **Fixed-Income Products:** Fixed and floating rates, bonds, swaps, caps and floors, FRAs and other delta products.
- **Yield, Duration and Convexity:** Definitions, use and limitations, bootstrapping to build up the yield curve from bonds and swaps.
- **Curve Stripping:** reference rates & basis spreads, OIS discounting and dual-curve stripping, cross-currency basis curve, cost of funds and the credit crisis.
- **Interpolation Methods:** piece wise constant forwards, piece wise linear, cubic splines, smart quadratics, quartics, monontone convex splines.
- **Current Market Practices:** Money vs. scrip, holiday calendars, business day rules, and schedule generation, day count fractions.
- **Stochastic Interest Rate Models, one and two factors:** Transferring ideas from the equity world, differences from the equity world, popular models, data analysis.
- **Calibration:** Fitting the yield curve in simple models, use and abuse.
- **Heath, Jarrow and Morton Model:** Modeling the yield curve. Determining risk factors of yield curve evolution and optimal volatility structure by PCA. Pricing interest rate derivatives by Monte Carlo.
- **The Libor Market Model:** (Also Brace, Gatarek and Musiela). Calibrating the reference volatility structure by fitting to caplet or swaption data.
- **Advanced Monte Carlo Techniques:** Low-discrepancy series for numerical quadrature. Use for option pricing, speculation and scenario analysis.
- **SABR Arbitrage Free SABR Model:** Managing volatility risks, smiles, local volatility models, reduction to the effective forward equation, arbitrage free boundary conditions.
- **Credit Risk and Credit Derivatives:** Products and uses, credit derivatives, qualitative description of instruments, applications.
- Structural and Intensity models used for credit risk.
- **CDS Pricing, Market Approach:** Implied default probability, recovery rate, default time modeling, building a spreadsheet on CDS pricing.
- **Synthetic CDO Pricing:** The default probability distribution, default correlation, tranche sensitivity, pricing spread.
- **Implementation:** CDO/copula modeling using spreadsheets.
- Correlation and State Dependence: correlation, linear correlation, analyzing correlation, sensitivity and state dependence.
- **Risk of Default:** The hazard rate, implied hazard rate, stochastic hazard rate and credit rating, capital structure arbitrage.
- **Copulas:** Pricing basket credit instruments by simulation.
- **Statistical Methods in Estimating Default Probability:** ratings migration and transition matrices and Markov processes.
- **X-Valuation Adjustment:** Background, default probability and exposure, collateral, CVA, regulatory requirements, DVA and FVA, Counterparty Lab in excel, credit default swaps, bootstrapping CDS spreads, interest rate swaps.

Module 6

Fixed Income and Credit

Preparatory Reading:

- Jon Gregory, *The xVA Challenge: Counterparty Credit Risk, Funding, Collateral and Capital*, third edition, 2015, Wiley (Chapters 4-7, 10, 12)
- Paul Wilmott, Paul Wilmott Introduces Quantitative Finance, 2007, Wiley (Chapters 14-19)
- Paul Wilmott, Paul Wilmott on Quantitative Finance, second edition, 2006, Wiley (Chapters 30-33, 36, 37, 39-42)
- Peter Jaeckel, Monte Carlo Methods in Finance, 2002, Wiley (Chapters 1-14)

Further Reading:

- Avinash K. Dixit and Robert S. Pindyck, *Investment Under Uncertainty*, 1994, Princeton University Press
- Darrell Duffie & Kenneth J. Singleton, *Credit Risk: Pricing, Measurement, and Management*, 2003, Princeton University Press
- Gunter Loffler and Peter Posche, *Credit Risk Modeling using Excel and VBA*, 2007, Wiley
- George Chacko et al., *Credit Derivatives: A Primer on Credit Risk, Modeling, and Instruments*, 2006, Wharton School Publishing (Chapters 3, 5)
- Philipp J. Schoenbucher, *Credit Derivatives Pricing Models: Model, Pricing and Implementation*, 2003, Wiley (Chapters 2, 4, 5)
- Antulio N. Bomfim, *Understanding Credit Derivatives and Related Instruments*, 2004, Academic Press (Chapters 15, 16, 17)
- Nassim Taleb, Dynamic Hedging, 1996, Wiley
- John C. Hull, Options, Futures and Other Derivatives, fifth edition, 2002, Prentice-Hall

Lifelong Learning Lectures:

(Available to Full program and Level II delegates)

- Jumps in Credit Risk Modeling. Intensity Models: Theory, Cailbration, Pricing - Wim Schouten
- The Pricing of CDOs using Levy Copulas - Wim Schouten
- Introduction to CVA - David Bakstein
- Credit Modelling - Claudio Albanese
- Term Sheets - Paul Wilmott
- Brace, Gatarek and Musiela - Timothy Mills
- Managing Smile Risk - Pat Hagan
- The Market Price of Risk - Paul Wilmott
- Fixed Income Modelling - Claudio Albanese
- Yield Curves via Static Hedging - Yury Rojek
- Tools and Methods for Quantitative Finance - Sebastien Lleo

Advanced Electives

In this module you choose two from the following online electives to specialize in your area of interest. You will be required to complete a practical project relating to the electives you have chosen.

Algorithmic Trading: The use of algorithms has become an important element of modern-day financial markets, used by both the buy side and sell side. This elective will look into the techniques used by quantitative professionals who work within the area.

- What is Algorithmic Trading
- Preparing data; Back testing, analysing results and optimisation
- Build your own algorithm
- Alternative approaches: Paris trading Options; New Analytics
- A career in Algorithmic trading

Advanced Computational Methods: One key skill for anyone who works within quantitative finance is how to use technology to solve complex mathematical problems. This elective will look into advanced computational techniques for solving and implementing math in an efficient and succinct manner, ensuring that the right techniques are used for the right problems.

- Finite Difference Methods (algebraic approach) and application to BVP
- Root finding
- Interpolation
- Numerical Integration

Advanced Risk Management: In this elective, we will explore some of the recent developments in Quantitative Risk Management. We take as a point of departure the paradigms on how market risk is conceived and measured, both in the banking industry (Expected Shortfall) and under the new Basel regulatory frameworks (Fundamentals Review of the Trading Book, New Minimum, Capital of Market Risk).

- Review of new developments on market risk management and measurement
- Explore the use of extreme value of theory (EVT)
- Explore adjoint automatic differentiation

Advanced Volatility Modeling: Volatility and being able to model volatility is a key element to any quant model. This elective will look into the common techniques used to model volatility throughout the industry. It will provide the mathematics and numerical methods for solving problems in stochastic volatility.

- Fourier Transforms
- Functions of a Complex Variable
- Stochastic Volatility
- Jump Diffusion

Machine Learning with Python: This elective will focus on Machine Learning and deep learning with Python applied to Finance. We will focus on techniques to retrieve financial data from open data sources.

- Using linear OLS regression to predict financial prices & returns
- Using scikit-learn for machine learning with Python
- Application to the pricing of the American options by Monte Carlo simulation
- Applying logistic regression to classification problems
- Predicting stock market returns as a classification problem
- Using TensorFlow for deep learning with Python
- Using deep learning for predicting stock market returns

Advanced Portfolio Management: As quantitative finance becomes more important in today's financial markets, many buy-side firms are using quantitative techniques to improve their returns and better manage client capital. This elective will look into the latest techniques used by the buy side in order to achieve these goals.

- Perform a dynamic portfolio optimization, using stochastic control
- Combine views with market data using filtering to determine the necessary parameters
- Understand the importance of behavioural biases and be able to address them
- Understand the implementation issues
- Develop new insights into portfolio risk management

Counterparty Credit Risk Modeling: Post-global financial crisis, counterparty credit risk and other related risks have become much more pronounced and need to be taken into account during the pricing and modeling stages. This elective will go through all the risks associated with the counterparty and how they are included in any modeling frameworks.

- Credit Risk to Credit Derivatives
- Counterparty Credit Risk: CVA, DVA, FVA
- Interest Rates for Counterparty Risk – dynamic models and modeling
- Interest Rate Swap CVA and implementation of dynamic model

Behavioural Finance for Quants: Behavioural finance and how human psychology affects our perception of the world, impacts our quantitative models and drives our financial decisions. This elective will equip delegates with tools to identify the key psychological pitfalls, use their mathematical skills to address these pitfalls and build better financial models.

- System 1 Vs System 2
- Behavioural Biases; Heuristic processes; Framing effects and Group processes
- Loss aversion Vs Risk aversion; Loss aversion; SP/A theory
- Linearity and Nonlinearity
- Game theory

R for Quant Finance: R is a powerful statistical programming language, with numerous tricks up its sleeves making it an ideal environment to code quant finance and data analytics applications.

- Intro to R and R Studio
- Navigate and understand packages
- Understand data structures and data types
- Plot charts, read and write data files
- Write your own scripts and code

Risk Budgeting: Rather than solving the risk-return optimization problem as in the classic (Markowitz) approach, risk budgeting focuses on risk and its limits (budgets). This elective will focus on the quant aspects of risk budgeting and how it can be applied to portfolio management.

- Portfolio Construction and Measurement
- Value at Risk in Portfolio Management
- Risk Budgeting in Theory
- Risk Budgeting in Practice

Fintech: Financial technology, also known as fintech, is an economic industry composed of companies that use technology to make financial services more efficient. This elective gives an insight into the financial technology revolution and the disruption, innovation and opportunity therein.

- Intro to and History of Fintech
- Fintech – Breaking the Financial Services Value Chain
- FinTech Hubs
- Technology – Blockchain; Cryptocurrencies; Big Data 102; AI 102
- Fintech Solutions
- The Future of Fintech

C++: Starting with the basics of simple input via keyboard and output to screen, this elective will work through a number of topics, finishing with simple OOP.

- Getting Started with the C++ Environment – First Program; Data Types; Simple Debugging
- Control Flow and Formatting – Decision Making; File Management; Formatting Output
- Functions – Writing User Defined Functions; Headers and Source Files
- Intro to OOP – Simple Classes and Objects
- Arrays and Strings