Master’s in Financial Engineering

Foundations of Buy-Side Finance:
Quantitative Risk and Portfolio Management

Spring 2008, Monday 7:10 pm – 9:30 pm, Room 303

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The course covers all the aspects of quantitative portfolio management and risk management from the foundations to the most advanced developments.

- Multivariate statistics: multivariate distributions, copulas, location-dispersion ellipsoid, measures of co-dependence
- Estimation techniques: non-parametric, maximum-likelihood under thick tails, shrinkage, robust, Bayesian, extreme value theory
- Market modeling: quest for invariance in different markets, factor models, principal component analysis, FFT projection, delta-gamma & Monte Carlo pricing
- Portfolio evaluation: stochastic dominance, indices of satisfaction, utility, value at risk, expected shortfall, coherent measures
- Allocation frameworks: trading/prospect theory, total return management, benchmark allocation
- Portfolio optimization under estimation risk: Black-Litterman, Bayesian, cone programming and robust optimization

The course consists of theory and applications. The theory follows closely the adopted textbook. The applications are implemented in MATLAB® (standard, statistics and optimization toolboxes required), displayed interactively during the course to support intuition and further analyzed by the students in their homework.

Prerequisites: multivariate calculus, linear algebra, basics of probability.
No knowledge of MATLAB is assumed.

Reading: Risk and Asset Allocation – Springer Quantitative Finance

Grading: 40% final exam
- 60% theory: in-class, pen & paper, open-book
- 40% practice: take-home project, MATLAB
50% home assignments
10% class participation

Teaching Assistant: TBD

Office hours: TBD
Lecture 1 – introduction

Contents
- Announcements and course overview
- Introduction to MATLAB
  - Set path and work from command window
  - Generate scripts
  - Generate functions
  - Debug
  - Plot 2D (lines, scatter plots, histograms)
  - Plot 3D (surfaces, histograms)
- Representations of univariate distributions
  - Probability density function
  - Cumulative distribution function
  - Quantile
  - Characteristic function
- Monte Carlo simulations
  - Dirac delta and generalized functions
  - Glivenko-Cantelli theorem
  - Empirical distribution
  - Histograms and pdf
  - Empirical cdf
  - Empirical quantile by interpolation
- Distribution of transformations of random variables
  - Invertible transformations
  - Positive affine transformations
- Summary statistics:
  - Location: mode, median, expected value
  - Scale: modal dispersion, range, variance
  - Higher moments
- Taxonomy of univariate distributions
  - Uniform distribution
  - Normal/Cauchy/ Student t distributions
  - Gamma distribution
  - Lognormal distribution

References: (!) = required, (?) = optional
- (!): A. Meucci, *Risk and Asset Allocation* – Springer:
  Preface, 1.1->1.3, 4.2 p.178-179, B.1, B.2
- A. Meucci, *Risk and Asset Allocation, Technical Appendices* – symmys.com:
  (!): wherever cited above;  (?): otherwise
- (!): Support materials for Lecture 1 – symmys.com

Lecture 1’ – MATLAB overview (taught by teaching assistant)
Lecture 2 – multivariate statistics I

Contents
- Representations of multivariate distributions
  ▪ Probability density function
  ▪ Cumulative distribution function
  ▪ Characteristic function
  ▪ Simulations and empirical distribution
- Copula-marginal factorization
  ▪ Marginal distributions
  ▪ Grades
  ▪ Copula representation via pdf and cdf
  ▪ Copula representation via simulations
  ▪ Co-monotonic random variables
- Conditional distribution
  ▪ pdf representation
  ▪ Bayes’rule
- Dependence and concordance summary statistics
  ▪ Special copulas
  ▪ Schweizer-Wolff measure
  ▪ Kendall tau
  ▪ Spearman rho
- Simulation of generic distributions via copula and quantile

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer:
  2.1->2.3, 2.5
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above;  (?): otherwise
- (!): Support materials for Lecture 2 – symmys.com
Lecture 3 – multivariate statistics II

Contents
- Shape summary statistics
  - Affine equivariance of shape statistics
  - Expected value – covariance
  - Mode – modal dispersion
- Location-dispersion ellipsoid
  - Spectral theorem
  - Statistical interpretation
- Pearson correlation: theory, practice and pitfalls
- Taxonomy of multivariate distributions
  - Normal distribution
  - Cauchy distribution
  - Student t distribution
  - Log-distributions
  - Uniform distribution
  - Wishart distribution

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer:
  2.4->2.6, A.1-> A.5
- (!): A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 3 – symmys.com
Lecture 4 – market modeling I

Contents
- Special classes of multivariate distributions
  - Order statistics
  - Elliptical distributions
  - Stable distributions
  - Infinitely divisible distributions
- The quest for invariance
  - Equities: log-returns
  - Fixed-income: changes in yield to maturity
  - Derivatives: changes in at-the-money implied volatility

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer: 2.6.8–>2.7; 3.1
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 4 – symmys.com

Lecture 5 – market modeling II

Contents
- Projection of invariants to the investment horizon
  - Convolution
  - Fourier transform
  - Analytical projection: characteristic function
  - Numerical projection: FFT
- Pricing of invariants at the investment horizon
  - Analytical: log-distributions for raw securities
  - Numerical: Monte Carlo
  - Approximate: theta-delta/vega-gamma
  - Approximate: carry-duration-convexity

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer: B3, B4, 3.2, 3.3
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 5 – symmys.com
Lecture 6 – market modeling III

Contents
- Dimension reduction, theory:
  - Multivariate market betas
  - Principal component analysis
- Dimension reduction, notable examples
  - Capital Asset Pricing Model
  - Arbitrage Pricing Theory
  - Fama-French factors
- Principal component analysis of the swap market
  - Level-slope-butterfly interpretation of the components
  - Continuum limit: Fourier basis and main frequencies

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer:
  A.1->A.5, 3.4, 3.5
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 6 – symmys.com

Lecture 7 – estimation I

Contents
- Estimators
  - general definitions
  - evaluation: bias, inefficiency, error
- Non-parametric estimators
  - Sample quantile and order statistics.
  - Sample mean/covariance and best-fitting ellipsoid
  - Sample factor loadings (betas) and OLS
- Maximum-likelihood estimators
  - Normal hypothesis: sample estimators
  - Non-normal hypothesis: outlier rejection

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer:
  4.1, 4.2, 4.3
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 7 – symmys.com
Lecture 8 – estimation II

Contents
- Shrinkage estimators
  ▪ Stein mean
  ▪ Ledoit-Wolf covariance
- Robust estimators
  ▪ Assessing robustness: the influence function
  ▪ Huber’s “M” robust estimators: location, scatter and betas
  ▪ Outlier detection and high-breakdown estimators
  ▪ Minimum-volume ellipsoid and minimum-covariance determinant
- Missing data: the EM algorithm

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer: 4.4, 4.5, 4.6
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 8 – symmys.com

Lecture 9 – estimation III

Contents
- Multivariate Bayesian estimation
  ▪ Theoretical background
  ▪ Analytical solutions: Normal-Inverse Wishart model
  ▪ Numerical solutions: Monte Carlo Markov Chains

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer: 7.1->7.4
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 9 – symmys.com
Lecture 10 – risk management I

Contents
- Investor’s objectives
  § Total return
  § Benchmark allocation
  § Net profits
- Global evaluation of a portfolio: stochastic dominance
- Summary evaluation of a portfolio: indices of satisfaction
  § Money-equivalence
  § Estimability
  § Sensibility
  § Consistence with stochastic dominance
  § Constancy
  § Positive homogeneity
  § Translation invariance
  § Sub- and super-additivity
  § Co-monotonic additivity
  § Concavity and convexity
  § Risk aversion, risk propensity and risk neutrality
- Expected utility and certainty-equivalent

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer: 5.1->5.4
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 10 – symmys.com
Lecture 11 – risk management II

Contents
- Quantiles and value at risk (VaR)
  ▪ Properties
  ▪ Analytical solutions
  ▪ Cornish-Fisher approximation
  ▪ Extreme value theory (EVT)
  ▪ Numerical solutions
- Coherent measures of performance
  ▪ Expected shortfall (ES) and conditional value at risk (CVaR)
  ▪ Spectral measures of performance

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer:
  5.5->5.6
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?) : otherwise
- (!): Support materials for Lecture 11 – symmys.com

Lecture 12 – portfolio optimization I

Contents
- Portfolio optimization theory
  ▪ Investor’s inputs: market, investment horizon, objectives and satisfaction
  ▪ Market inputs: distribution of prices at the horizon, transaction costs
- Constrained optimization: computationally tractable problems
  ▪ Linear and quadratic programming
  ▪ Second order and semi-definite cone programming
- Two-step optimization
  ▪ Analytical solutions
  ▪ Numerical solutions
- Benchmark vs. total-return portfolio management
  ▪ Mean-variance approximation
  ▪ Analytical solutions in total-return coordinates
  ▪ Analytical solutions in relative-return coordinates:
    expected outperformance, tracking error, information ratio
  ▪ Pitfalls of the mean-variance approach

References: (!) = required, (?) = optional
- A. Meucci, Risk and Asset Allocation – Springer:
  (!): 6.1->6.7
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?) : otherwise
- (!): Support materials for Lecture 12 – symmys.com
Lecture 13 – portfolio optimization II

Contents
- Prior allocation
- Sample-based allocation
  - Error in satisfaction and constraint assessment
  - Leverage of estimation risk
- Alternative optimization methods
- Allocations as decisions
  - Opportunity cost
  - Allocation decisions evaluated as estimators

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer:
  8.1 -> 8.3
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support materials for Lecture 13 – symmys.com

Lecture 14 – portfolio optimization III

Contents
- Bayesian allocation
  - Predictive return allocation
  - Classical-equivalent allocation
- Black-Litterman allocation
  - Views on market parameters
  - Views on the market realizations
- Copula-opinion pooling allocation
- Resampled allocation
- Robust allocation
  - Second-order cone programming problems
  - Semi-definite programming problems
- Robust Bayesian allocation

References: (!) = required, (?) = optional
- (!): A. Meucci, Risk and Asset Allocation – Springer:
  9.1 -> 9.5
- A. Meucci, Risk and Asset Allocation, Technical Appendices – symmys.com:
  (!): wherever cited above; (?): otherwise
- (!): Support material for Lecture 14 – symmys.com