15.968 Analytics of Finance II

Course Description. This course covers the practical aspects of the analytics of finance, i.e., how it is used in practice. To that end, all of the topics covered—investment strategies, backtest simulation, data and computational architecture, portfolio construction, trading implementation, and risk management—will be developed in the context of a specific quantitative equity trading strategy. Because concepts are most easily grasped in the particular context in which they are applied, the course is designed to follow the natural sequence of research, development, testing, and implementation for a quantitative investment manager. While the objective of this course is far broader than simply to train students in the art and science of investment management, organizing the material in this manner will provide students with a clearer and more stimulating sense of industry practice. Mathematical and statistical techniques will be covered in some depth—along with their computational implementation in Matlab—however, the emphasis will be on financial *applications*, not on methodology.

Pre-requisites. This course is intended primarily for M.Fin. students, however, others may enroll with the permission of the instructor. Therefore, the pre-requisite is 15.415 or its equivalent (15.401 or 15.414), and the educational background of students in the M.Fin. program. 15.433, 15.437, and 15.450 are recommended courses that are highly complementary to 15.968. Some rudimentary programming skills will be necessary—projects will make extensive use of Matlab, though no prior exposure to this language is necessary.

Course Requirements and Grading. Course requirements include: regular attendance and class preparation/participation in lectures and recitations (10 percent), four group projects (50 percent), and a final examination (40 percent). *The closed-book final examination will be given during the MIT-scheduled final examination date—please reserve this date immediately and schedule your interviews and travel plans accordingly.*

Course Materials. The following materials will be used in this course (required texts are indicated by asterisks):

- Lo and Mende*, 2011, *15.968 Lecture Notes.* MIT CopyTech.
- Lo, 2010, *Hedge Funds: An Analytic Perspective*, Princeton.
- Campbell, Lo, and MacKinlay*, 1997, *The Econometrics of Financial Markets*, Princeton.

Class Preparation and Participation. Class preparation and participation are important components of this course. Students are expected to come to each class well prepared to discuss the materials assigned (see the attached *15.968 Reading List*). In addition, there may be short assignments distributed in each class for discussion during the following class. Such assignments are to be treated like "case-study" assignments that require considerable advance preparation, and students should expect to be "cold-called" in class to present their analyses of these assignments.

Group Projects. There are four group projects that will provide students with additional opportunities to apply the methods covered in the lectures. Each project covers a specific aspect of the quantitative trading strategy around which the course is organized. Students will be assigned to project groups based on computer skills, industry experience, etc. so that each group will have a good balance of quantitative expertise and institutional background. The four projects and their distribution and due dates are:

Project	Topic	Distributed	Due
A	Introduction to a Mean Reversion Strategy	February 1	March 1
B	Backtest Analysis of a Mean Reversion Strategy	March 1	March 29
C	Implementation of a Mean Reversion Strategy	March 29	April 26
D	Risk Management and Performance Attribution	April 26	May 3

Projects are due at the start of class (4:00pm) on the due date. Projects submitted after the due date will be subject to a 25% grade-deduction for each 24-hour period they are late. There will be no exceptions to this policy.

Classroom Values@MITSloan. Throughout this class, we plan to adhere to the policies and procedures outlined in the "Classroom Values@MITSloan" document which is included at the end of this syllabus for your convenience. Please make sure you read it and understand how it applies to this class.

15.968 List of Topics

1. Mathematical and Statistical Preliminaries

a. Course overview, and the role of mathematics and statistics in financial analysis
b. Classical vs. Bayesian statistical inference
c. Common estimation methods (ML, GMM)
d. Asymptotic theory
e. Review of stochastic processes and financial time series

2. Market Efficiency, Behavioral Finance, and Practice

a. Classical and modern notions of market efficiency
b. Tests of efficiency and rationality
c. Behavioral finance
d. Evolutionary psychology, sociobiology, and neuroeconomics
e. The Adaptive Markets Hypothesis

3. Hedge Funds, Proprietary Trading, and Investment Management

a. Industry overview and introduction to quantitative strategies
b. Matching investment objectives to risk/reward profiles
c. Mean reversion, momentum, and other dynamic trading strategies
d. Anatomy of an equity market-neutral trading strategy
e. Degrees of "arbitrage" and their limits

4. The Econometrics of Backtest Simulations

a. Definitions of "backtesting"
b. Look-ahead, overfitting, and other data-snooping biases
c. Bayesian decision theory and sequential analysis
d. Monte Carlo simulation
e. Rejecting the Random Walk Hypothesis

5. Forecasting Risk and Return

a. Properties of risk and return distributions
b. Forecast quality, forecast horizons, and scaling
c. Estimating linear factor models and covariance matrices
d. Estimating nonlinear and nonparametric factor models
e. Estimating stochastic volatility and GARCH models

6. Data Architecture and Strategy Design

a. Data sources, data vendors, and data quality
b. Introduction to data architecture
c. Data and computational architecture of a quantitative strategy
d. Data domains: market, model, portfolio
e. Tick data, trading technology, and beyond

7. Portfolio Construction

a. Portfolio objectives, constraints, and optimization
b. Trade-selection and trading-sizing algorithms
c. Risk models and market models
d. Limits to diversification
e. Optimal trading rules, turnover, trade frequency, and calculational complexity

8. Trading Implementation

a. Overview of market microstructure, market-making, and high-frequency trading
b. Econometric models of market microstructure and trading costs
c. Calibration, stress testing, and testability of trading algorithms
d. Steady-state performance and transients, failure mode design, stability of parameters
e. Control, tracking, and performance attribution for live and shadow portfolios

9. Risk Management

a. Leverage, liquidity, capacity, margin, cash management, and capital allocation
b. Normal markets, extreme markets, and rare events
c. Insurance, hedging, shaping the return profile
d. Risk and human behavior
e. Physics envy and the uncertainty checklist

10. Open Questions and Parting Thoughts

a. What caused the financial crisis?
b. Where do models go when they die?
c. Is proprietary trading ethical?
d. What will happen to the quants in August 2020?
e. Can financial engineering cure cancer, stop global warming and solve the energy crisis?

15.968 Readings

1. Mathematical and Statistical Preliminaries

Cox, D., 1990, "Role of Models in Statistical Analysis," *Statistical Science* 5, 169–174.

* Leamer, E., 1983, "Let's Take the Con Out of Econometrics," *American Economic Review* 73, 31–43.

* Merton, R., 1994, "Influence of Mathematical Models in Finance on Practice: Past, Present, and Future," *Philosophical Transactions of the Royal Society of London* A 347, 451–463.

Silvey, S., 1975, *Statistical Inference*. London: Chapman and Hall.

2. Market Efficiency, Behavioral Finance, and Practice

* Bossaerts, P., 2009, "What Decision Neuroscience Teaches Us About Financial Decisionmaking," *Annual Review of Financial Economics* 1, 383–404.

Boudoukh, J., Richardson, M., Shen, Y. and R. Whitelaw, 2007, "Do Asset Prices Reflect Fundamentals? Freshly Squeezed Evidence from the OJ Market," *Journal of Financial Economics* 83, 397–412.

* Brennan, T. and A. Lo, 2010, "The Origin of Behavior," to appear in *Quarterly Journal of Finance*.

Camerer, C., Loewenstein, G. and D. Prelec, 2005, "Neuroeconomics: How Neuroscience Can Inform Economics," *Journal of Economic Literature* 43, 9–64.

Farmer, D., 2002, "Market Force, Ecology and Evolution," *Industrial and Corporate Change* 11, 895–953.

Lo, A., 2004, "The Adaptive Markets Hypothesis: Market Efficiency from an Evolutionary Perspective," *Journal of Portfolio Management* 30, 15–29.

* Lo, A., 2005, "Reconciling Efficient Markets with Behavioral Finance: The Adaptive Markets Hypothesis," *Journal of Investment Consulting* 7, 21–44.

Roll, R., 1984, "Orange Juice and Weather," *American Economic Review* 74, 861–880.

Shefrin, H., 2005, *A Behavioral Approach to Asset Pricing*. Amsterdam: Elsevier.

3. Hedge Funds, Proprietary Trading, and Investment Management

Fung, W. and D. Hsieh, 1997, "Empirical Characteristics of Dynamic Trading Strategies: The Case of Hedge Funds," *Review of Financial Studies* 10, 275–302.

Jegadeesh, N. and S. Titman, 2001, "Profitability of Momentum Strategies: An Evaluation of Alternative Explanations," *Journal of Finance* 56, 699–720.

Lo, A., 2010, *Hedge Funds: An Analytic Perspective*. Princeton, NJ: Princeton University Press.

* Lo, A., 2008, "Where Do Alphas Come From?: A New Measure of the Value of Active Investment Management," *Journal of Investment Management* 6, 1–29.

* Lo, A. and C. MacKinlay, 1990, "When Are Contrarian Profits Due to Stock Market Overreaction?" *Review of Financial Studies* 3, 175–206.

* Richardson, M. and J. Stock, 1990, "Drawing Inferences from Statistics Based on Multiyear Asset Returns," *Journal of Financial Economics* 25, 323–348.

Treynor, J. and F. Black, 1973, "How to Use Security Analysis to Improve Portfolio Selection," *Journal of Business* 46, 66–86.

4. The Econometrics of Backtest Simulation

Boyle, P., Broadie, M. and P. Glasserman, 1997, "Monte Carlo Methods for Security Pricing," *Journal of Economic Dynamics and Control* 21, 1267–1321.

* Foster, D. and R. Stine, 2008, "α-investing: A Procedure for Sequential Control of Expected False Discoveries," *Journal of the Royal Statistical Society*, Series B, 70, Part 2, 429–444.

Goodwin, T., 1998, "The Information Ratio," *Financial Analysts Journal* 54, 34–43.

Lo, A., 1994, "Data-Snooping Biases in Financial Analysis," in H. Russell Fogler, ed.: *Blending Quantitative and Traditional Equity Analysis*. Charlottesville, VA: Association for Investment Management and Research.

* Lo, A., 2002, "The Statistics of Sharpe Ratios," *Financial Analysts Journal* 58, 36–52.

* Lo, A. and C. MacKinlay, 1990, "Data Snooping Biases in Tests of Financial Asset Pricing Models," *Review of Financial Studies* 3, 431–468.

5. Forecasting Risk and Return

* Ait-Sahalia, Y. and A. Lo, 1998, "Nonparametric Estimation of State-Price Densities Implicit in Financial Asset Prices," *Journal of Finance* 52, 499–548.

* Ang, A. and G. Bekaert, 2002, "International Asset Allocation With Regime Shifts," *Review of Financial Studies* 15, 1137–1187.

Hamilton, J., 1989, "A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle," *Econometrica* 57, 357–384.

* Pan, J., 2002, "The Jump-Risk Premia Implicit in Options: Evidence from an Integrated Time-Series Study," *Journal of Financial Economics* 63, 3–50.

6. Data Architecture and Strategy Design

* Chen, P., 1976, "The Entity-Relationship Model—Toward a Unified View of Data, *ACM Transactions on Database Systems* 1, 9–36.

* Dacorogna, M., R. Gençay, U. Müller, R. Olsen and O. Pictet, 2001, *An Introduction to High-Frequency Finance*, Chapters 4, 11. San Diego: Academic Press.

7. Portfolio Construction

* Black, F. and R. Litterman, 1992, "Global Portfolio Optimization," *Financial Analysts Journal* 47, 28–43.

Brennan, T. and A. Lo, 2010, "Impossible Frontiers," *Management Science* 56, 905–923.

Brennan, T., Lo, A. and T. Nguyen, 2010, "Portfolio Theory: A Review," MIT LFE Working Paper No. 2011–04–123.

* Goldfarb, D. and G. Iyengar, 2003, "Robust Portfolio Selection Problems," *Mathematics of Operations Research* 28, 1–38.

Grinold, R. and R. Kahn, 1999, *Active Portfolio Management: A Quantitative Approach for Producing Superior Returns and Controlling Risk.* New York: McGraw-Hill.

* Kan, R. and G. Zhou, 2007, "Optimal Portfolio Choice with Parameter Uncertainty," *Journal of Financial and Quantitative Analysis* 42, 621–656.

Litterman, R., 2003, *Modern Investment Management: An Equilibrium Approach*. New York: John Wiley & Sons.

Michaud, R. and R. Michaud, 2008, "Estimation Error and Portfolio Optimization: A Resampling Solution," Journal of Investment Management 6, 8–28.

8. Trading Implementation

Almgren, R. and N. Chriss, 2000, "Optimal Execution of Portfolio Transactions," *Journal of Risk* 3, 5–39.

* Bertsimas, D. and A. Lo, 1998, "Optimal Control of Execution Costs," *Journal of Financial Markets* 1, 1–50.

Bertsimas, D., Kogan, L. and A. Lo, 2000, "When Is Time Continuous?", *Journal of Financial Economics* 55, 173–204.

Kaminski, K. and A. Lo, 2010, "When Do Stop-Loss Orders Stop Losses?", preprint, MIT Laboratory for Financial Engineering.

Kirilenko, A., Kyle, A., Samadi, M. and T. Tugkan, 2010, "The Flash Crash: The Impact of High Frequency Trading on an Electronic Market," available at SSRN: http://ssrn.com/abstract=1686004.

* Lo, A., MacKinlay, C. and J. Zhang, 2002, "Econometric Models of Limit-Order Execution Times," *Journal of Financial Economics* 65, 31–71.

* Pérold, A., 1988, "The Implementation Shortfall: Paper vs. Reality," *Journal of Portfolio Management* 14, 4–9.

Roll, R., 1984, "A Simple Implicit Measure of the Effective Bid–Ask Spread in an Efficient Market," *Journal of Finance* 39, 1127–1139.

9. Risk Management

* Dai, J. and S. Sundaresan, 2010, "Risk Management Framework for Hedge Funds Role of Funding and Redemption Options on Leverage," preprint, March.

Fielding, E., Lo, A. and H. Yang, 2010, "The National Transportation Safety Board: A Model for Systemic Risk Management," to appear in *Journal of Investment Management*.

* Getmansky, M., Lo, A. and I. Makarov, 2004, "An Econometric Analysis of Serial Correlation and Illiquidity in Hedge-Fund Returns," *Journal of Financial Economics* 74, 529–609.

* Lo, A. and M. Mueller, 2010, "WARNING: Physics Envy May Be Hazardous To Your Wealth," *Journal of Investment Management* 8, 13–63.

Lo, A. and D. Repin, 2002, "The Psychophysiology of Real-Time Financial Risk Processing," *Journal of Cognitive Neuroscience* 14, 323–339.

Lo, A., Repin, D. and B. Steenbarger, 2005, "Fear and Greed in Financial Markets: An Online Clinical Study," *American Economic Review* 95, 352–359.

10. Open Questions and Parting Thoughts

Gentile, M., 2010, *Giving Voice to Values*. New Haven, CT: Yale University Press.

* Fernandez, J. and A. Lo, 2011, "Securitizing a Cure for Cancer," unpublished working paper.

* Khandani, A. and A. Lo, 2007, "What Happened to the Quants in August 2007?," *Journal of Investment Management* 5, 29–78.

* Khandani, A. and A. Lo, 2011, "What Happened to the Quants in August 2007?: Evidence from Factors and Transactions Data," *Journal of Financial Markets* 14, 1–46.

Lo, A., 2011, "Business Ethics: A Cognitive Sciences Perspective", unpublished working paper.

Course Schedule

Note: This is an *approximate* schedule for the course and meant to serve as a very rough guide to the pace of the course; some material may take longer or shorter to cover than the allotted time.

Lectures:

Session	Date	Topic	Assignment
1	Feb 1	Mathematical and Statistical Preliminaries	Project A posted
2	Feb 8	Motivation, Market Efficiency, and Practice	
3	Feb 15	Hedge Funds, Proprietary Trading, and Investment Management, Part 1	
	Feb 22	**No class; Monday schedule**	
4	Mar 1	Hedge Funds, Proprietary Trading, and Investment Management, Part 2	Project A due, Project B posted
5	Mar 8	The Econometrics of Backtest Simulation	
	Mar 15, 22	**No class; SIP and Spring Break**	
6	Mar 29	Forecasting Risk and Return	Project B due, Project C posted
7	Apr 5	Data Architecture and Strategy Design	
8	Apr 12	Portfolio Construction	
	April 19	**No class; Patriot's Day**	
9	Apr 26	Trading Implementation	Project C due, Project D posted
10	May 3	Risk Management	Project D due
11	May 10	Open Questions and Parting Thoughts	

Recitations:

Session	Date	Topic
1	Feb 4	Review of probability and statistics and Lecture 1.
2	Feb 11	Introduction to financial databases.
3	Feb 18	Introduction to Matlab; Project A Q&A.
	Feb 25	**No recitation**
4	Mar 4	Review of Project A.
5	Mar 11	Review of backtesting, Project B Q&A.
	Mar 18, 25	**No recitation**
6	Apr 1	Review of Project B.
7	Apr 8	Review of database programming.
8	Apr 15	Project C Q&A.
	Apr 22	**No recitation**
9	Apr 29	Review of Project C. Project D Q&A.
10	May 6	Review of Project D.

Classroom Values@MITSloan

The MIT Sloan Mission *http://mitsloan.mit.edu/about/mission.php*

The mission of the MIT Sloan School of Management is to develop principled, innovative leaders who improve the world and to generate ideas that advance management practice.

Values@MIT Sloan

https://sloanpoint.mit.edu/administration/values/Pages/default.aspx

The MIT Sloan Mission statement (above) provides the context for core values that express who we are at our best. These core values include ***integrity, respect, collaboration, innovation,*** and ***positive impact.*** We invite all members of our community – students, staff, faculty, alumni – to practice these values in all the ways we work together, both inside and outside of the classroom.

MIT Sloan Policy on Classroom Behavior

In order to create a productive learning environment and to ensure mutual respect it is essential that the norms and rules of classroom etiquette and behavior reflect the highest standards. It is also important that these norms be consistently enforced by the faculty across all classes. Although in the final analysis each faculty member is responsible for his or her own classroom, there are significant negative consequences for other faculty and for the School if rules are not consistent and are not enforced. Therefore it is the policy of the MIT Sloan School that

- Students are expected to arrive promptly on time and to stay for the entire class.
- Faculty are expected to begin and end class on time.
- Laptops and e-readers not be open in the classroom except with explicit permission of the faculty (e.g., when used to deliver an e-course pack or otherwise used as part of the instructional program or when required by students because of physical or other challenges)
- Cellphones and PDAs are not to be used or permitted to ring in the classroom.
- Students are expected to attend all classes.

It is expected that faculty will articulate how these rules apply in their class as well as how the rules will be enforced.

MIT Sloan Career Development Office Recruiting Policy

Students are required to schedule campus interviews outside of scheduled class times and to make every attempt to schedule second round interviews and site visits outside of class times. Classes missed for such activities are *not* excused absences and may count against your participation grade.

ACADEMIC HONESTY – INTEGRITY IN PRACTICE

As a member of the MIT Sloan academic community, you are expected to uphold the highest standards of academic integrity. Violations of academic integrity include, but are not limited to, cheating, plagiarism, unauthorized collaboration, and facilitating academic dishonesty. Please see the document Academic Integrity at the Massachusetts Institute of Technology: A Handbook for Students for further discussion of this topic. These standards are also discussed below, specifically regarding plagiarism, individual work, and team work.

It is your responsibility to make yourself aware of MIT's rules of academic integrity and to adhere to them. When students are found to have violated academic standards, disciplinary action will result. Possible consequences include grade reduction, an F grade, a transcript notation, delay of graduation, or expulsion from MIT.

This discussion of academic integrity below is not exhaustive, and there may be areas that remain unclear to you. ***If you are unsure whether some particular course of action is proper, it is your responsibility to consult with your professor and/or teaching assistant for clarification.***

Plagiarism

Plagiarism occurs when you use another's intellectual property (words or ideas) and do not acknowledge that you have done so. Plagiarism is a very serious offense. If it is found that you have plagiarized -- deliberately or inadvertently -- you will face serious consequences, as indicated above.

The best way to avoid plagiarism is to cite your sources - both within the body of your assignment and in a bibliography of sources you used at the end of your document.

Materials gathered through research via the Internet must be cited in the same manner as more traditionally published material. Lack of such citation constitutes plagiarism.

To review rules of citation: http://libguides.mit.edu/content.php?pid=80743&sid=598642

Individual Assignments

Many assignments in MIT Sloan courses are expected to be done individually. The information below outlines what is meant by "individual" work. These rules should be observed unless otherwise defined by the instructor.

When you are asked to do ***individual*** work, you are expected to adhere to the following standards:

- Do not copy all or part of another student's work (with or without "permission").
- Do not allow another student to copy your work.
- Do not ask another person to write all or part of an assignment for you.
- Do not work together with another student in order to answer a question, or solve a problem, or write a computer program jointly.

- Do not consult or submit work (in whole or in part) that has been completed by other students in this or previous years for the same or substantially the same assignment.
- Do not use print or internet materials directly related to a case/problem set unless explicitly authorized by the instructor.
- Do not use print or internet materials without explicit quotation and/or citation.
- Do not submit the same, or similar, piece of work for two or more subjects without the explicit approval of the two or more instructors involved.

Please note that many classes will require a combination of team work and individual work. *Be sure that you follow all the guidelines for individual work when a faculty member identifies an assignment as an individual one.*

Team Assignments

When you are asked to ***work in teams***, there is a broad spectrum of faculty expectations. Three general types of appropriate collaboration on team assignments are described below. The instructor will indicate in the syllabus what his/her expectations are. If there is any uncertainty, it is the student's responsibility to clarify with the professor or TA the type of team work that is expected.

Type 1 collaboration:
The professor states that collaboration is allowed, but the final product must be individual. An example of this might be a problem set.

- You are allowed to discuss the assignment with other team members and work through the problems together.
- What you turn in, however, must be your own product, written in your own handwriting, or in a computer file of which you are the sole author.
- Copying another's work or electronic file is not acceptable.

Type 2 collaboration:
The professor states that collaboration is encouraged but that each person's contribution to a given deliverable does not have to be substantial (allowing groups to take a "divide and conquer" approach). An example of this might be a brief progress report that is part of a more extensive collaboration (as a whole, the more extensive collaboration may be Type 3).

- Each team member is encouraged to contribute substantially to the team assignment, however, the team may choose to assign one or more team members to prepare and submit the deliverable on behalf of the team.
- Regardless of how work is shared or responsibilities are divided among individual team members, each member of the team will be held accountable for the academic integrity of the entire assignment. If, for example, one member of the team submits plagiarized work on behalf of the team, the entire team will be subject to sanctions as appropriate.
- The team may not collaborate with other students outside of the team unless the professor explicitly permits such collaboration.

Type 3 collaboration:
The professor states that collaboration is expected and that each team member must contribute substantially to the deliverable. An example of this might be the 15.311 OP project.

- Each team member must make a substantial contribution to the assignment. It is not, for example, acceptable to divide the assignments amongst the team members (e.g., part of the team completes the OP Project while the rest of the team prepares a team case for DMD),

though the team may divide the work of any one assignment to complete it as they deem appropriate.

- The team may not collaborate with other students outside of the team unless the professor explicitly permits such collaboration.

If you are unsure whether some particular form of interaction is proper in individual or team work, it is your responsibility to consult the instructor and/or teaching assistant for clarification and guidance.