IE 524 – Optimization in Finance, Fall 2014, Syllabus

General as in the Previous Years

Textbook:
Optimization Methods in Finance,
Gerard Cornuejols and Reha Tutuncu, Cambridge Univ. Press, 2007 Required!

Reference:
Introduction to Operations Research,

Credit: 4 Graduate Hours.

Prerequisite: FIN 500 (Introduction to Finance) and MATH 415 (Applied Linear Algebra).

Course Description: Basic optimization models; Theory and methods for financial engineering including linear, quadratic, nonlinear, dynamic, integer, and stochastic programming; Applications to portfolio construction and rebalancing, optimal hedging, index tracking, algorithmic trading, asset management, arbitrage detection, option pricing and risk management; Optimization software for classes of optimization problems. Projects involve building optimization models based on financial market data and solutions using optimization solvers.

Specifics This Semester: Fall, 2014

Meeting Time and Location: MW 3:00-4:40pm (with break); 218 Ceramics Building

Instructor: Yu-Ching Lee, Ph.D., ylee77@illinois.edu, 214 Transportation; Office Hour: Tuesdays 1:00-2:00pm or “By Appointment.”

Teaching Assistant: Jung Mok Ma, jma15@illinois.edu, 416 Transportation; Office Hour: Mondays 1:00pm-2:00pm

Course Format
The lectures are expected to be a combination of handouts delivering, blackboard writing, and slides displaying. Taking (some) classroom notes should be helpful.
Computer Techniques:
To solve different types of the optimization problems in finance, you may use the following skills:

(1) AMPL: with the solvers on NEOS
- Recommended for solving small instances of Linear Program (LP), Nonlinear Program (NLP), Quadratic Program (QP), Quadratic Constrained Program (QCP), Integer Program (IP), Mixed Integer Program (MIP), Complementarity Problem (CP).

Action (Required):
- Bring your laptop on the day of Lecture 3 so you can practice it immediately

(2) CPLEX C++ library: on Visual Studio (VC++.Net)
- Recommended for solving large instances especially of LP, IP, and MIP.

Action (Required):
- Please install Visual Studio in your laptop soon. (If you use a Mac, you may want to install Virtual Box and create a Virtual Machine (VM) of Windows OS and install Visual Studio within the VM)
- Please download and install CPLEX that fits your OS and Visual Studio in your laptop before Lecture 7.
- Bring your laptop on the day of Lecture 7 so you can practice it immediately.

(3) Others: SDPA on NEOS
- Recommended for solving small instances of Semidefinite Program (SDP)

Homework:
There should be 8-9 Homework. The highest 8 scores will be counted toward the final grades. Announced in class and on Compass 2g. The homework is due 1 week after announcement. Graded by TAs, and returned after 1 week. No late homework is accepted.

Group Project (VC++.Net project, technical report, and oral presentation):
Announced after midterm. Report due on 12/01 midnight via electronic submission. Presentations held on 12/03 and 12/08. 3-5 people per group (9-15 groups). Each group could choose from two different topics as the project topic. The two topics have to be equally chosen. If not, groups will be selected by drawing lots.

Grading Weights:
Project 20%; Homework 40%; Midterm Exam (Monday, Oct. 13) 20%; Final Exam (as scheduled by University) 20%. *Final exam is not cumulative.

**Letter Grade:**
A+: 93 and above. A : 85-92 (round to the nearest integer) A- : 80-84 B+: 75-79  
B : 70-74 B- : 65-69 C+: 60-64 C : 55-59 C- : 50-54 D+: 45-49 
D : 40-44 D- : 35-39 F : 34 and below

**Calendar:**
For holidays and the academic calendar, check out: http://illinois.edu/calendar/list/557
For MSFE events, check out: http://msfe.illinois.edu/

**Academic Integrity and Student Responsibilities:**
Cheating in any format is prohibited, and is subject to the University Procedures and Sanctions as defined in the Part 4 of Article 1 “Student Rights and Responsibilities”:
http://www.admin.illinois.edu/policy/code/article1_part4_1-401.html

**Topics and Homework Assignments Schedule:**

<table>
<thead>
<tr>
<th>Lecture No.</th>
<th>date</th>
<th>Topic</th>
<th>HW Announce ment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture 1</td>
<td>08/25</td>
<td>Syllabus and Introduction to Optimization</td>
<td>HW0</td>
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<tr>
<td>Lecture 2</td>
<td>08/27</td>
<td>Modeling and Basics of Linear Programming (LP)</td>
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<td>Labor Day (No class)</td>
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<tr>
<td>Lecture 3</td>
<td>09/03</td>
<td>Using Optimization Solvers on NEOS and Coding the Model in AMPL</td>
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<tr>
<td>Lecture 4</td>
<td>09/08</td>
<td>Sensitivity Analysis of LP in Short-Term Financing</td>
<td>HW1</td>
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<td>Lecture 5</td>
<td>09/10</td>
<td>Duality of LP</td>
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<td>Lecture 6</td>
<td>09/15</td>
<td>Asset Pricing with Arbitrage Detection using an LP Model</td>
<td>HW2</td>
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<tr>
<td>Lecture 7</td>
<td>09/17</td>
<td>Calling CPLEX in a C++ Project—Demo on Visual Studio</td>
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<td>Lecture 8</td>
<td>09/22</td>
<td>1. Basics of Piecewise Linear Model</td>
<td>HW3</td>
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<td>2. GARCH Parameter Selection using a Nonlinear Programming (NLP) Model</td>
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<td>Lecture 9</td>
<td>09/24</td>
<td>Basics of Quadratic Programming (QP)</td>
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<td>Lecture 10</td>
<td>09/29</td>
<td>QP application: Mean-Variance Optimization for Portfolio</td>
<td>HW4</td>
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<tr>
<td>Lecture</td>
<td>Date</td>
<td>Selection</td>
<td>Notes</td>
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<tr>
<td>11</td>
<td>10/01</td>
<td>More on QP applications: Sharpe Ratio Maximization, Estimation of the Linear Factor Model of Return, and Risk-Neutral Probabilities Recovery</td>
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<tr>
<td>12</td>
<td>10/06</td>
<td>On Applications of the Semidefinite Programming (SDP) &amp; Second-Order Cone Programming (SOCP)---Index Tracking Portfolio Optimization, Risk-Neutral Probabilities Recovery Revisit, Covariance Matrix Approximation.</td>
<td>HW5</td>
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<td>10/08</td>
<td>Review</td>
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<td>10/13</td>
<td>Midterm</td>
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<td>13</td>
<td>10/15</td>
<td>Midterm discussion, Project discussion</td>
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<td>14</td>
<td>10/20</td>
<td>Basics of Integer Programming (IP)</td>
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<td>15</td>
<td>10/22</td>
<td>IP Applications: Combinatorial auctions, Lockbox site selection, Index-Fund Construction, Characterized index-fund construction</td>
<td>HW6</td>
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<tr>
<td>16</td>
<td>10/27</td>
<td>IP Solution Techniques: Lagrangian Relaxation, Bender’s Decomposition, Dantzig-Wolfe Decomposition</td>
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<td>17</td>
<td>10/29</td>
<td>Basics of Dynamic Programming (DP) and Application in American Options’ optimal exercising plan</td>
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<tr>
<td>18</td>
<td>11/03</td>
<td>Collateralized Mortgage Obligations (CMO) Issuer’s Optimization Problem using a DP model</td>
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| 19       | 11/05  | 1. More on DP application: Derivation of Euler Equation  
2. Complementarity Problems, Nash Equilibrium, and the Application in American Options pricing. | HW7       |
|          | 11/10  | Stochastic Programming sec.1 by professor Jerome Kreuser                   |           |
| 20       | 11/12  | Stochastic Programming sec.2 by professor Jerome Kreuser                   |           |
| 21       | 11/17  | Stochastic Programming sec.3 by professor Jerome Kreuser                   |           |
| 22       | 11/19  | Stochastic Programming sec.4 by professor Jerome Kreuser                   |           |
|          | 11/24  | Thanksgiving break (no class)                                             |           |
|          | 11/26  | Thanksgiving break (no class)                                             |           |
| 24       | 12/01  | Stochastic Programming sec.5 by professor Jerome Kreuser                   |           |
| 25       | 12/03  | Group Presentations Topic 1                                               |           |
| 26       | 12/08  | Group Presentations Topic 2                                               |           |
|          | 12/10  | Review                                                                    |           |
Detailed Contents:

1. Linear Programming
   a. Models, LP feasible polyhedron, Graphical solution method, Definition of the basic feasible solution, Degeneracy, Slack, Basis (matrix), Reduced cost, Optimal Condition
   c. Dual problem, Definition of the marginal opportunity cost (“shadow price”), Weak duality theorem, Strong duality theorem, Complementarity slackness, Relationship between primal and dual optimum
   d. In FE: short-term financing, cash-flow matching
   e. In FE: Arbitrage Detection in European options (also talking about asset pricing, pricing principles, definition of the risk-neutral probabilities, price of the European options) and Arbitrage Detection in foreign currency exchange.
   f. Piecewise linear optimization
   g. Computer technique: AMPL
   h. Computer technique: CPLEX C++ library

2. Nonlinear Programming
   2-1 General Nonlinear Programming
      a. GARCH parameter selection (also talking about the derivation of GARCH model)
      b. Classifications of the NLP models: unconstrained/constrained NLP, smooth/nonsmooth NLP, convex/nonconvex NLP
      c. Computer technique: various solvers on NEOS

2-2 Quadratic Programming
   a. Convexity, Local/Global optimum, Solution uniqueness, KKT condition
   b. In FE: Markowitz’s Mean-Variance Optimization in portfolio optimization, Definition of admissible portfolio, Definition of efficient portfolio, Definition of efficient frontier
   c. In FE: Additional to the Mean-Variance Optimization: Diversification, Turnover constraint, Imposing transaction costs
   d. In FE: Sharpe-Ratio for portfolio selection, Capital allocation line (CAL), Sharpe-Ratio maximization and its QP reformulation
   e. In FE: Estimation of the Linear factor model of return
   f. In FE: Recovering risk-neutral probabilities (RNP) from the observed price of the options (also talking about the definition of the spline function, relationship between spline function and RNP)
      g. Group project topic 1: Constructing efficient portfolio

2-3 Conic Programming:
a. Semidefinite Programming (SDP), Second-Order Cone Programming (SOCP), Transform a convex QCQP into SDP
b. In FE: Index-tracking portfolio construction and its SOCP Reformulation
c. In FE: Enforcing the nonnegative constraint of the spline function (RNP recovery problem revisit) by SDP, adjusting the Covariance matrix by SDP
d. Computer technique: SDPA on NEOS

3. Integer Programming
   a. Models, Binary variables, Big-M technique, Solution property, Branch-and-Bound
   b. In FE: Capital budgeting problems, Combinatorial auctions, Lockbox allocation problem, Index fund construction, Characterized index-fund construction,
   c. IP Solution techniques: Lagrangian Relaxation, Benders’ decomposition (“Benders’ cut”), Dantzig-Wolfe decomposition (“column generation”)
   d. Group project topic 2: Constructing Index Fund

4. Dynamic Programming
   a. Terminology (State, Action, Stage, Decision, Value function, Backward Recursion (“Bellman equation”), Bounding condition)
   b. In FE: American options’ optimal exercising plan, American call option theorem
   c. In FE: Option pricing in DP framework (also talking about the Binomial Lattice model of the stock price, log compounded-factor)
   d. In FE: Collateralized Mortgage Obligations (CMO), Resecuitization, Tranches, CMO construction (also talking about the weighted average life (WAL), Principal and interest (P&I) analysis, Amortization, Z-tranche)
   e. In ECON: Derivation of Euler Equation for Consumption

5. Complementarity Problems
   a. Definition of the Nash equilibrium, Formulation of the Nash equilibrium
   b. In FE: American Options pricing (also talking about the Black-Sholes partial differential operator)
   c. Computer technique: AMPL and solvers on NEOS

6. Stochastic Programming (See below the invited lectures.)

Invited Lectures
We will have Professor Dr. Jérôme L Kreuser on campus to give a total of 5 invited lectures on

Stochastic Programming in Finance. (The lecture on 12/01 is expected to be moved forward as an extension of one of the lectures on 11/10, 12, 17 or 19. The exact date, time, and location should be determined later in the semester.) There will be 1-2 Homework sets and several exam questions on this topic as well. Abstract provided by Prof. Kreuser is as follows.
Syllabus

Stochastic Programming in Finance

Fall 2014  Jerome L Kreuser

The purpose of these sessions is to form a solid framework for applied stochastic programming in asset liability management. They will enhance your understanding of why it is important, when to use it, how to use it, and framing and interpreting real applications.

In these sessions, we will cover material from Chapters 16-18 of Cornuejols and Tütüncü but go beyond. Our focus will be on real applications. Theory and algorithms will be invoked when necessary to understand and interpret results. Selected readings will be provided for each of the topic sessions below and selected materials may be omitted given time constraints. It will be intense.

**Five Modules**

1. The failure of finance.
   - Stochastic programming: what it is and why it is important in correcting the failures.
2. Back to the future and the failure of history.
   - Growing, grafting, trimming trees – the hard work.
   - Anchoring in the future instead of the past and “making history rhyme”.
   - Integrating many factors, economic and financial theories, and regimes.
3. The taming of the zoo; Black Swans, Dragon Kings, and long-tailed beasts. Can we tame them? Yes, we can!
4. Building a model model (Part I)
   - Events and the conservation of financial flows.
   - Scenarios and/or trees – dissecting the forest.
   - Shaping the distribution: shortfall, upfall, shortfalls, CVaR and other measures.
   - What to do when you don’t know what to do: Kelly or max expected log.
5. Building a real model (Part II – selected example/s)
   - What you got when you get it; optimality, duality, state-space prices, implied prices, and their uses and abuses.
   - Risk management in public institutions is different; each one is different in its own way.
   - Reinsurance models with really big fat tails.