S9: Financial Physics (C.J. Foot, TT 2013, Oxford Physics)

Summary: An introduction to the physics-based approach to finance theory (so-called 'Econophysics'). This interdisciplinary field aims to apply ideas and mathematical techniques developed in physics (particularly those related to statistical mechanics) to improve our understanding of the empirically observed fluctuations in global financial markets. Emphasis is placed on the extent to which asset prices deviate from random walk behaviour, and the minimization or *hedging* of financial risk.

IMPORTANT NOTE:

Agent-based models (covered in Ch. 4 of ref. [1]) will not be covered in lectures **or examined.**

Introduction

This course follows the book written by the previous lecturer Neil Johnson (and his co-authors) [1] and some of the lecture notes are essentially the typescript of the book. The material covered this year includes chapters 1, 2, 3 and some of chapter 6, viz. sections 6.1, 6.2, 6.3 (Figs. 6.1 – 6.4), and a bit of 6.4. Additional examinable material will also be included in notes on: *Forward contracts, Put-call Parity, Mathematical solution of the Black-Scholes equation (as in ref.* [2]*), The binomial tree model, Implied Volatility* (as in Fig. 6.11 in ref. [1]), and *Credit Default Swaps.* The approach of Johnson et al can be characterised as Econophysics. A more rigorous mathematical approach is well described in Wilmott et al [2] (Wilmott has written other useful books). The book by J.C. Hull [3] has good explanations and interesting 'business snapshots' as well as very explicit instructions (like a manual that might be used in accountancy) on how to price certain financial instruments such a Credit Default Swaps. The notes for the Financial Mathematics lectures in the Maths Dept are also available online [4] (within Oxford) but unsurprisingly these are very 'mathematical', and physicists are unlikely to be familiar with the mathematical background that is assumed, e.g. probability theory. Reference [5] is a recent textbook with a very good introduction to probability and stochastic calculus for physicists however it is mostly for a more advanced course, e.g., there is a chapter on the Levy statistics.

With some exceptions, this course uses the same notation as in the book and past exams but this appears not to be standard notation, e.g. as found on the Wikipedia entry about the Black-Scholes equation, or [4].

[1] Financial Market Complexity: What Physics can tell us about market behaviour.
Neil F. Johnson, P. Jefferies and Pak Ming Hui. Oxford University Press, 2003 ISBN: 0198526652

[2] The Mathematics of Financial Derivatives. P. Wilmott, S. Howison, and J. Dewynne.
Cambridge University Press, 1996.

[3] Options, Futures, and other Derivatives. J.C. Hull. Pearson, 8th edition, 2012.

http://www.rotman.utoronto.ca/~hull/ofod/index.html
[This website has lecture notes (Powerpoint slides) for each chapter of the book.]

[4] B10b Mathematical Models of Financial Derivatives. http://www.maths.ox.ac.uk/courses

[5] Stochastic Processes for Physicists, understanding noisy systems. K. Jacobs. CUP 2010

The contents of the lectures are given overleaf retaining the numbering of the book chapters. (Ch. 4, 5, 7 of the book at not included in this course.)

The lectures follow the same order as the material in the book with the additional lecture notes that I have written being inserted along the way.

Chapter 1 *Financial markets as complex systems*

- 1.1 Real problems in finance
- 1.2 Complex systems and Complexity
- 1.3 Financial market overview
  - 1.3.1 The role of financial centres
  - 1.3.2 Types of financial market
  - 1.3.3 Financial assets
    - 1.3.3.1 Debt, equity and foreign exchange
    - 1.3.3.2 Time of settlement
    - 1.3.3.3 Obligation to exchange
  - 1.3.4 Financial market agents
    - 1.3.4.1 Market service providers
    - 1.3.4.2 Market service users
  - 1.3.5 The price of an asset
    - 1.3.5.1 Role of the market-maker
    - 1.3.5.2 Demand for assets
  - 1.3.6 Orders and market clearing
    - 1.3.6.1 Market impact
    - 1.3.6.2 Clearing the market
  - 1.3.7 Chartism vs. fundamentalism
- 1.4 Observing the market

Chapter 2 *Standard finance theory*

- 2.1 The problem for standard finance theory
- 2.2 Taking a random walk
  - 2.2.1 Back to basics
  - 2.2.2 Price-changes over one timestep
  - 2.2.3 Price-changes over multiple timesteps
    - 2.2.3.1 Implications for risk
    - 2.2.3.2 Statistical properties of the moments
    - 2.2.3.3 Probability distribution function: PDF
    - 2.2.3.4 Central Limit Theorem
  - 2.2.4 Continuous-time evolution equation for the PDF of price-changes
  - 2.2.5 Stochastic differential equations for the evolution of the price
- 2.3 Risk: tails of the unexpected
- 2.4 Eliminating risk within the Black-Scholes option pricing theory
  - 2.4.1 Introducing derivatives
    - 2.4.1.1 Futures and forwards
    - 2.4.1.2 Options
  - 2.4.2 Types of options
  - 2.4.3 Going, going, gone: the magic of zero risk

Chapter 3 *A complex walk down Wall Street*

- 3.1 Facing the stylized facts
- 3.2 Statistical tools and datasets
- 3.3 Empirical analysis
- 3.4 Challenging the standard theory
- 3.5 Toward a general stochastic process framework
- 3.6 Effects of temporal correlations in a market
  - 3.6.1 Winning by losing
  - 3.6.2 Drawdowns and crashes

[Skip Ch. 4,5]

Chapter 6 *Non-zero risk in the real world*

- 6.1 The other side of derivatives
- 6.2 Hedging to reduce risk
- 6.3 Zero risk?
- 6.4 Pricing and hedging with real-world asset movements **(up to and including 6.4.3)**

Lecture Notes

- *Put-call parity* - references [2] and [3]
- *Solving the Black-Scholes eqn by showing that it is equivalent to the diffusion eqn*
- *The binomial tree model: a simple example of pricing financial derivatives*
- *Implied Volatility* (refs. [2] and [3])
- *Credit Default Swaps* **(**reference [3], Hull)

Non-examinable: *Brownian motion: the Langevin equation and recent expts. Examples from physics.*