

Financial Physics

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The course has 7 handouts which are Chapters from the textbook shown above:
Financial Market Complexity: What Physics can tell us about market behaviour
 Oxford University Press, 2003 ISBN: 0198526652
 by Neil F. Johnson, P. Jefferies and Pak Ming Hui

This is a course about financial markets ... for physicists. It is not surprising to find courses on quantitative finance run by economists, mathematicians, and even computer scientists – but physicists? There is a simple reason, or rather a simple ‘complex’ reason. Financial markets are complicated, dynamical systems which are continually generating high-frequency data-series. This data records the aggregate action of the market’s many participants, each of who is trying to win in this vast global ‘game’. In fact it can be argued that financial markets provide the most well-documented, and longest running, record of a large-scale ‘complex system’. In short, financial markets constitute a real-world complex system which is continually evolving, which has significant practical importance, and which produces an enormous amount of data – and that’s the appeal.

It has been said that being a successful investor is like being a successful burglar. Most burglars know how to get into a building, and what to take - but only the successful ones know how, and most importantly *when*, to get out. ‘Time’ is therefore crucial in financial markets. Since our goal is to understand *real-world* markets as opposed to idealized ones, time also takes centre-stage in this book. Time relates to dynamics, and it is this evolving complex-system dynamics which underpins our scientific interest in financial markets.

Most, if not all, standard finance courses make some kind of apparently innocuous assumptions about market dynamics. For example they assume that the markets are in some kind of steady state or represent a stationary process, and that there are no implicit temporal correlations - or at best, that these correlations are of a specific type. As we show in the present course, these assumptions can give misleading answers to practical problems such as minimizing financial risk, coping with extreme events such as crashes or drawdowns, and pricing derivatives in non-ideal markets. Having said this, standard finance theory usually works. But it is the ‘usually’ that we are interested in – or rather the ‘unusually’. We focus on how and why real financial markets deviate from the standard finance theory paradigm of random-walk behaviour, and the consequences of such deviation. In particular, we will be interested in the tails of the distribution of price returns, and in the dynamics induced by crowd-like behaviour in markets. The consequences for managing risk will also feature quite prominently. In short, the following questions provide the focus of this course: *How* do financial markets behave? *Why* do financial markets behave in the way that they do? *What* can we do to minimize risk, given this behaviour?

The relationship between science, and in particular physics, and finance is still in the courtship phase – hence the (not so) occasional squabbles. Despite the immaturity of this so-called Econophysics field, there are many people interested in knowing more about it, including practitioners and students. A common request is ‘where can we learn about these Econophysics ideas, and how to implement them?’ The latter part of this request, concerning implementation, motivated us to give this course. In particular, we felt that there was a need to produce a course which takes a relatively small number of topics – the essential ones in our opinion - and treats them as thoroughly as possible.

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Not all the Chapters in the book will be covered in this course since this would create an overload of material. Instead, the course material consists of, and is restricted to, the following:

In addition to **Handout 1** (which is the one you are reading now), there is **Handout 2** (referred to as ‘Chapter 1’), **Handout 3** (referred to as ‘Chapter 2’), **Handout 4** (referred to as ‘Chapter 3’), **Handout 5** (referred to as ‘Chapter 4’), **Handout 6** (referred to as ‘Chapter 6’), and **Handout 7** (referred to as ‘Chapter 7’). I hope this isn’t too confusing – I believe that changing things around would have introduced too many typos.

After discussing the background to the concept of complexity and the structure of financial markets in **Handout 2** (labelled as ‘Chapter 1’), **Handout 3** (labelled as ‘Chapter 2’) examines the assumptions upon which standard finance theory is built. Reality sets in with **Handout 4** (labelled as ‘Chapter 3’), where we analyze data from two seemingly different markets and uncover certain universal features which cannot be explained within standard finance theory. **Handout 5** (labelled as ‘Chapter 4’) marks a significant departure from the philosophy of standard finance theory, being concerned with exploring microscopic models of markets which are faithful to real market microstructure yet which also reproduce the real-world statistical features discussed in Handout 4. **Handout 6** (labelled as ‘Chapter 6’) moves to the practical problem of how to quantify and hedge risk in real-world markets. **Handout 7** (labelled as ‘Chapter 7’) discusses deterministic descriptions of market dynamics, incorporating the topics of chaos and the all-important phenomena of market crashes.

The course was given for the first time in 2002, hence there are several past Finals papers available for viewing.

**The course material in these Handouts is self-contained.
Not all the material in these Handouts is required knowledge for the course – I will indicate in lectures what is required, and what constitutes additional reading which you may find interesting but which will not be examined.**

Also see the website of the new interdisciplinary finance research center involving Physics-Maths-Computing, the Oxford Centre for Computational Finance www.occf.ox.ac.uk

CONTENT OF COURSE/BOOK

HANDOUT 1 *This handout*

HANDOUT 2 ('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

HANDOUT 3 ('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

HANDOUT 4 ('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

HANDOUT 5 ('Chapter 4') *Financial market models with global interactions*

- 4.1 A bottom-up approach
- 4.2 Two's company, but three's a crowd
- 4.3 "To bar, or not to bar ..."
- 4.4 From the bar to the market
 - 4.4.1 What is the global information in a financial market?
 - 4.4.2 How do financial market agents decide how to trade?
 - 4.4.3 How do financial market agents 'win'?
 - 4.4.4 What else is missing?
 - 4.4.4.1 Agent wealth
 - 4.4.4.2 Trading timescales
- 4.5 Choosing a model
- 4.6 The 'El Farol Market Model'
 - 4.6.1 Specifying the model
 - 4.6.2 Parametrizing the model
 - 4.6.3 Reproducing the stylized facts
- 4.7 Dynamics of the 'El Farol Market Model'
- 4.8 Statics of the 'El Farol Market Model': the origins of volatility
 - 4.8.1 Numerical results for the volatility
 - 4.8.2 Qualitative explanation for the variation of volatility
 - 4.8.3 Quantitative explanation for the variation of volatility
 - 4.8.3.1 Analytic form for volatility in the crowded regime
 - 4.8.3.2 Analytic form for volatility in the dilute regime

HANDOUT 6 ('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
 - 6.4.1 Variation of wealth
 - 6.4.2 Price for a real-world option
 - 6.4.3 Implementing the real-world pricing formula
 - 6.4.4 Quantifying the risk analytically
 - 6.4.5 Risk-minimizing hedging strategy
 - 6.4.6 Implementing the optimal strategy
 - 6.4.6.1 Using real data
 - 6.4.6.2 Using surrogate data

- 6.4.6.3 Implementation
- 6.4.7 The residual risk
- 6.4.8 Risk premium
- 6.4.9 Black-Scholes as a special case
 - 6.4.9.1 The option price
 - 6.4.9.2 The hedging strategy
 - 6.4.9.3 The residual risk
- 6.4.10 Expanding around the Black-Scholes result
 - 6.4.10.1 Expansion of the option price
 - 6.4.10.2 Expansion of the optimal hedging strategy

HANDOUT 7 ('Chapter 7') *Deterministic dynamics, chaos and crashes*

- 7.1 Living with non-linearity
- 7.2 Non-linear dynamical models for finance and economics
 - 7.2.1 $n = 1$ dimensional systems: continuous time
 - 7.2.2 $n = 2$ dimensional systems: continuous time
 - 7.2.3 $n = 3$ dimensional systems: continuous time
 - 7.2.4 $n \geq 1$ dimensional systems: discrete time
- 7.3 Financial crashes and drawdowns
 - 7.3.1 Extreme behaviour
 - 7.3.2 Signs of a crash
 - 7.3.3 Birth and recurrence of crashes
- 7.4 Predicting the future: Who wants to be a Millionaire?

SOME ADDITIONAL TEXTS REFERRED TO IN THE HANDOUTS

(These are not required texts; just listed for interest)

[WDH] *The mathematics of financial derivatives*, P. Wilmott, J. Dewynne and S. Howison (Cambridge University Press, 1996).

[BP] *Theory of financial risks*, J.P. Bouchaud and M. Potters (Cambridge University Press, 2000).

[MS] *An introduction to Econophysics*, R.N. Mantegna and H.E. Stanley (Cambridge University Press, 2000).

[W] *Derivatives*, P. Wilmott (Wiley, 1998).

[G] *The nature of mathematical modelling*, N. Gershenfeld (Cambridge University Press, 1999).

[F] *An introduction to probability theory and its applications*, W. Feller (Wiley, 1968).

[V] *The statistical mechanics of financial markets*, J. Voit (Springer, 2001).

[S] *Non-linear dynamics and chaos*, S. Strogatz (Perseus, 2001).

[So] *Critical phenomena in natural sciences: chaos, fractals, self-organization and disorder*, D. Sornette (Springer, 2000).

[CLM] *The econometrics of financial markets*, J.Y. Campbell, A.W. Lo and A.C. MacKinlay (Princeton University Press, 1997).

[P] *Finance & financial markets*, K. Pilbeam (Macmillan business, 1998).