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DYNAMICS OF MARKETS

The New Financial Economics

SECOND EDITION

This second edition presents the advances made in finance market analysis since 2005. The book provides a careful introduction to stochastic methods along with approximate ensembles for a single, historic time series.

This new edition explains the history leading up to the biggest economic disaster of the 21st century. Empirical evidence for finance market instability under deregulation is given, together with a history of the explosion of the US Dollar worldwide. A model shows how bounds set by a central bank stabilized foreign exchange in the gold standard era, illustrating the effect of regulations. The book presents economic and finance theory thoroughly and critically, including rational expectations, cointegration, and ARCH/GARCH methods, and replaces several of those misconceptions with empirically based ideas.

This book will interest finance theorists, traders, economists, physicists and engineers, and leads the reader to the frontier of research in time series analysis.

JOSEPH L. MCCAULEY is Professor of Physics at the University of Houston, and is an advisory board member for the Econophysics Forum. He has contributed to statistical physics, the theory of superfluids, nonlinear dynamics, cosmology, econophysics, economics, and finance theory.

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'A thought provoking book. It does not only argue convincingly that the 'King – of orthodox economic theory – is naked', but offers a challenging economic alternative interpretation regarding especially the dynamics of financial markets.'

Giovanni Dosi, Laboratory of Economics and Management, Sant'Anna School of Advanced Studies, Pisa

'The heart of McCauley's book is a closely-reasoned critique of financial-economic mathematical modeling practice. McCauley's demonstration of the incompatibility between the assumptions of market-clearing equilibrium and informational efficiency is stunning, and sheds much-needed light on the mathematical modeling failures revealed by the financial melt-down. His unvarnished criticisms of neoclassical economic doctrine deserve equal attention. McCauley opens the windows of the self-referential world of economics to the fresh air of a mathematical physics point of view grounded in economic history and common sense. Neither monetarist, neoclassical, nor Keynesian schools of economics will take much comfort from McCauley's work, but they all have a lot to learn from it.'

Duncan K. Foley, Leo Model Professor, New School for Social Research and External Professor, Santa Fe Institute

'McCauley's mathematically and empirically rigorous Dynamics of Markets is one of those rare works which is challenging, not only to an intellectual orthodoxy (neoclassical economics), but also to its fledgling rival (econophysics). Neoclassical economics and finance theory receive justifiably dismissive treatments for failing empirically, but some econophysics contributions also distort empirical data– notably McCauley shows that "fat tails" in data can be the result of applying an unjustified binning process to nonstationary data. McCauley's essential messages for the future of economics after the Global Financial Crisis is that "There is no statistical evidence for Adam Smith's Invisible Hand", and that the hand that does exist and must be understood is both non-stationary and far from equilibrium.'

Steve Keen, School of Economics and Finance, University of Western Sydney

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For my stimulating partner Cornelia, who worked very hard
and effectively helping me to improve the text in both editions,
and for our sons, Finn and Hans.

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Preface to the second edition

This book provides a thorough introduction to econophysics and finance market theory, and leads the reader from the basics to the frontiers of research. These are good times for econophysics with emphasis on market instability, and bad times for the standard economic theory that teaches stable equilibrium of markets. I now explain how the new volume differs in detail from the first edition.

The first edition of *Dynamics of Markets* (2004) was based largely on our discovery of diffusive dynamics of the exponential model, and more generally on the dynamics of Markovian models with variable diffusion coefficients. Since that time, the progress by the University of Houston Group (Kevin Bassler, Gemunu Gunaratne, and me) has produced a far more advanced market dynamics theory based on our initial discovery. The present book includes our discoveries since 2004. In particular, we've understood the limitations of scaling and one-point densities: given a scaling process, only the one-point density can scale, the transition density and all higher-order densities do not and cannot scale, and a one-point density (as Hänggi and Thomas pointed out over 30 years ago) cannot be used to identify an underlying stochastic process. Even pair correlations do not scale. It follows that scaling cannot be used to determine the dynamics that generated a time series. In particular, scaling is not an indication of long time correlations, and we exhibit scaling Markov models to illustrate that point. Our focus in this edition is therefore on the pair correlations and transition densities for stochastic processes, representing the minimum level of knowledge required to identify (or rule out) a class of stochastic processes.

The central advances are our 2007 foreign exchange (FX) data analysis, and the Martingale diffusion theory that it indicates. We therefore focus from the start on the pair correlations of stochastic processes needed to understand and characterize a class of stochastic processes. The form of the pair

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correlations tells us whether we're dealing with Martingale dynamics, or with the dynamics of long time pair correlations like fractional Brownian motion. The stochastic processes with pair correlations agreeing empirically with detrended finance data are Martingales, and the addition of drift to a Martingale yields an Ito process. We therefore emphasize Ito processes, which are diffusive processes with uncorrelated noise increments. Stated otherwise, the Martingale is the generalization of the Wiener process to processes with general (x,t)-dependent diffusion coefficients. In physics x denotes position; in finance and macroeconomics x denotes the logarithm of a price.

A much more complete development of the theory of diffusive stochastic processes is provided in this text than in the first edition, with simple examples showing how to apply Ito calculus. We show that stationary markets cannot be efficient, and vice versa, and show how money could systematically be made with little or no risk by betting in a stationary market. The Dollar on the gold standard provides the illuminating example. The efficient market hypothesis is derived as a Martingale condition from the absence of influence of the past on the future at the level of pair correlations. Because of non-stationarity, the analysis of an arbitrary time series is nontrivial. We show how to construct an approximate ensemble for a single historic time series like finance data, and then show how a class of dynamical models can be deduced from the statistical ensemble analysis. Our new FX data analysis is discussed in detail, showing that the dynamics in log returns is a Martingale after a time lag of 10 minutes in intraday trading, and we show how spurious stylized facts are generated by a common but wrong method of data analysis based on time averages.

Here are some main points from each chapter. In Chapter 1 physics is contrasted with economics, and Wigner's description of the basis in symmetry for natural law is surveyed. We point out that some sort of regularity in a time series is required if a model is to be deduced. Chapter 2 introduces neo-classical economics and its falsification by Osborne. Increments, pair correlations, and transition densities are developed as the basis for the theory of stochastic processes in Chapter 3, where enlightening and nonstandard derivations of Kolmogorov's two partial differential equations (pdes) are provided. Chapter 4 provides a solid basis for much in the rest of the text. Therein, we explain both stationary and efficient markets and show how one excludes the other, and generalize the neo-classical notion of "value" to uncertain markets. The efficient market hypothesis is derived from the assumptions that past returns are uncorrelated with future returns increments, and an error in Fama's discussion is corrected. Standard misconceptions about market equilibrium and stability are exposed and dispelled. Chapter 5

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covers standard topics like the Capital Asset Pricing Model and the original Black–Scholes model. Chapter 6 covers scaling processes and also fractional Brownian motion in detail, and shows why transition densities and pair correlations cannot scale for a "scaling process," relegating scaling to no interest when the aim is to identify the dynamics from a time series. Statistical ensembles and their basis in vanishing correlations of initial data are presented in fairly complete detail in Chapter 7. An approximate statistical ensemble is constructed for the analysis of a single, historic time series, where it's shown that certain averages can be reliably measured, others not. Regularities in traders' daily behavior are reflected in the time variation of the ensemble average diffusion coefficient of the Martingale describing the finance market. I also show how and why standard time averages ("sliding windows") on nonstationary time series cannot be expected to converge to any limit in probability. I use our FX analysis to illustrate the basis for pinning down classes of mathematical models in the social sciences and beyond. I then show how spurious stylized facts like fat tails and misleading Hurst exponents are generated when time averages are used on nonstationary time series. Volatility is introduced and discussed (and is discussed in detail in Chapter 10). In Chapter 8 I provide a basic introduction to generalized Black–Scholes option pricing for arbitrary Ito processes, and show that for arbitrary drift and diffusion coefficients the generalized Black–Scholes pde yields Martingale option prices. We discuss how invalid liquidity assumptions can lead to market crashes, and begin to discuss the derivatives-based credit bubble that burst in September, 2008. Chapter 9 presents the history of the Dollar and FX since the gold standard as the prime example of the instability generated by deregulation, and ends with a discussion of the worldwide financial crisis and the money supply. The main point, illustrated by the Dollar on and off the gold standard, is that markets without strong regulations can be expected to show instability. The notion that deregulation and free trade are maximally beneficial to society is a neo-classical assumption with nations taken as agents. We discuss the mortgage credit bubble and shadow banking, and why credit creation has exploded worldwide via derivatives. Chapter 10 presents standard econometric methods of regression analysis in macroeconomic theory, based on the untenable assumption of market stability. Cointegration and integration I(d) are presented, and the inapplicability of those assumptions to real data are discussed. I show that the Lucas policy critique is based on a severely restricted and nonempirically based monetary model, and explain via counterexamples that nonstationarity in empirical data cannot be eliminated by cointegration in regression analysis. ARCH and GARCH regression models are shown to violate observed Martingale finance markets. The final

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chapter on complexity is an enlargement of the original one, and includes the idea of emergence (in biology).

In short, we offer an alternative to the standard macroeconomic theory, which is based on overly restrictive regression models, and we name this alternative "The New Financial Economics." This is one step toward the goal stated in *Nature* (Ball, 2006), that econophysics will eventually replace micro- and macroeconomic theory in both the classrooms and the boardrooms. This second edition appears at the right time, when ordinary people (if not academic theorists) are questioning the use of ad hoc models as the basis for finance trading, and are questioning the assumption that unregulated markets provide the best of all possible worlds as their jobs are transferred eastward to cheaper, unorganized labor. The lessons of the local labor battles in the west from the early part of the twentieth century, where unions had to be established so that workers could gain a living wage from the owners of capital, have been lost. With the fall of the Berlin Wall in 1989, and then the USSR in 1991, it was largely assumed that *laissez faire* had triumphed as regulated Europe began to follow Reagan-Thatcher-Friedman policies and deregulate, but the failed promise of Pareto optimality of the *laissez faire* program has now been exposed by the popping of the worldwide credit bubble. Deregulation has helped the east, and has hurt the west. The big question is how ordinary workers will make a living in the future. Such questions are not discussed in financial engineering classes. The student who wants to learn financial engineering is advised to put away this book, which focuses on understanding markets rather than on making ad hoc models to sell to well-heeled buyers, and instead to consult one of the many fine financial math books available (e.g. Baxter and Rennie, 1995).

This book can be studied as follows. First, for the mathematically challenged reader, Chapters 1, 2, 4, and 9 can be read while ignoring the math. In Chapters 1, 3, 4, 6, 7, and 9 the math and main ideas are fully developed. Chapter 7 is the high point, but Chapter 9 broadens the perspective from FX markets to the role of the money supply in international trade and finance. Chapters 1–5 provide a basic introduction to elementary ideas of finance combined with the math. The original Black–Scholes model in Chapter 5 can be understood by restricting the math in Chapter 3 to basic Ito calculus and the Fokker–Planck equation. Chapter 10 requires Chapters 3 and 7 as background, and is further illuminated by the analysis of Chapter 9. The one-semester econophysics course at the University of Houston consists regularly of Chapters 1 and 2 (lightly covered), Chapters 4–8 (heavily covered). Chapter 9 (which began as an invited talk for the 2007 Geilo NATO-ASI)

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was included once. Chapter 10 was developed later. Chapter 11 presents my understanding of complexity in dynamics.

Chapter 3 is quite long because it's unusually complete; topics are included there that are either hard or impossible to find in other texts. Through Chapter 5, the following parts can be ignored: 3.5–3.53, 3.6.8–9, 3.7.4, 3.9. For Chapter 6 one needs part 3.6.9. For Chapter 7 one needs parts 3.5–3.5.3 and 3.6.8. Chapter 8 is based on Section 3.9.

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