

**ON THE NATURE OF THE STOCK MARKET:
SIMULATIONS AND EXPERIMENTS**

by

Hendrik J. Blok

B.Sc., University of British Columbia, 1993
M.Sc., University of British Columbia, 1995

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Bibliography

- [1] D. Sornette, A. Johansen, and J.-P. Bouchaud. Stock market crashes, precursors and replicas. *J. Phys. I France*, 6:167–75, 1996.
- [2] Swiss Franc-U.S. Dollar tickwise exchange rate data, 1985–1991. Available from <http://www.stern.nyu.edu/~aweigend/Time-Series/Data/SFR-USD.Tickwise.gz>, provided by Andreas Weigend.
- [3] Dow Jones Industrial Average: Daily close, 1896–1999. Available from <http://www.economagic.com/em-cgi/data.exe/djind/day-djiac>, provided by Economagic.com.
- [4] Rama Cont, Marc Potters, and Jean-Philippe Bouchaud. Scaling in stock market data: Stable laws and beyond. arXiv:cond-mat/9705087, 1997.
- [5] Benoit B. Mandelbrot. *Fractals and Scaling in Finance: Discontinuity, Concentration, Risk*. Springer-Verlag, New York, 1997.
- [6] P. Gopikrishnan, M. Meyer, L. A. N. Amaral, and H. E. Stanley. Inverse cubic law for the distribution of stock price variations. *Eur. Phys. J. B*, 3:139–40, 1998.
- [7] Parameswaran Gopikrishnan, Vasiliki Plerou, Luís A. Nunes Amaral, Martin Meyer, and H. Eugene Stanley. Scaling of the distribution of fluctuations of financial market indices. *Phys. Rev. E*, 60:5305–16, 1999. arXiv:cond-mat/9905305.
- [8] O. G. Mouritsen. *Computer Studies of Phase Transitions and Critical Phenomena*. Springer-Verlag, Berlin, Heidelberg, 1984.
- [9] B. B. Mandelbrot. The variation of certain speculative prices. *J. Business*, 36:394–419, 1963.
- [10] Rosario N. Mantegna and H. Eugene Stanley. Scaling behaviour in the dynamics of an economic index. *Nature*, 376:46–9, 1995.

- [11] P. Bak, C. Tang, and K. Wiesenfeld. Self-organized criticality: An explanation of $1/f$ noise. *Phys. Rev. Lett.*, 59:381–4, 1987.
- [12] P. Bak, C. Tang, and K. Wiesenfeld. Self-organized criticality. *Phys. Rev. A*, 38:364–74, 1988.
- [13] D. Sornette, A. Johansen, and I. Dornic. Mapping self-organized criticality onto criticality. *J. Phys. I France*, 5:325–35, 1995. <http://alf.nbi.dk/~johansen/Papers/nosoc.ps.gz>.
- [14] Hendrik J. Blok and Birger Bergersen. Synchronous versus asynchronous updating in the “game of life”. *Phys. Rev. E*, 59:3876–9, 1999. <http://rikblok.cjb.net/lib/blok99.html>.
- [15] Gold–silver price ratios, 1257–1999. Available from <http://www.globalfindata.com/freecom.htm>, provided by Global Financial Data.
- [16] S. Grossman. On the efficiency of competitive stock markets where trades have diverse information. *J. Finance*, 31:573–85, 1976.
- [17] M. Youssefmir, B. A. Huberman, and T. Hogg. Bubbles and market crashes. <ftp://parcftp.xerox.com/pub/dynamics/bubbles.ps>, 1994.
- [18] T. Hogg, B. A. Huberman, and M. Youssefmir. The instability of markets. <ftp://parcftp.xerox.com/pub/dynamics/bubbles.ps>, 1995.
- [19] David P. Brown and Zhi Ming Zhang. Market orders and market efficiency. *J. Finance*, 52:277–308, 1997.
- [20] W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery. *Numerical Recipes in C: The Art of Scientific Computing*. Cambridge University Press, Cambridge, second edition, 1992. <http://www.nr.com>.
- [21] B. M. Gammel. Hurst’s rescaled range statistical analysis for pseudorandom number generators used in physical simulations. *Phys. Rev. E*, 58:2586–2597, 1998.
- [22] Makoto Matsumoto and Takuji Nishimura. Mersenne twister: A 623-dimensionally equidistributed uniform pseudo-random number generator. *ACM Transactions on Modeling and Computer Simulations*, 8:3–30, 1998. <http://www.math.keio.ac.jp/~nisimura/random/doc/mt.ps>.
- [23] John M. Dutton and William H. Starbuck, editors. *Computer simulation of human behavior*, New York, 1971. Wiley.

- [24] Thomas M. Cover and Joy A. Thomas. *Elements of Information Theory*. John Wiley and Sons, New York, 1991.
- [25] Edwin T. Jaynes. Probability theory: The logic of science. <http://bayes.wustl.edu/etj/prob.html>, 1996.
- [26] Mark B. Garman. Market microstructure. *J. Fin. Econ.*, 3:257–275, 1976.
- [27] R. G. Palmer, W. B. Arthur, J. H. Holland, B. LeBaron, and P. Taylor. Artificial economic life: A simple model of a stockmarket. *Physica D*, 75:264–74, 1994.
- [28] M. Levy, H. Levy, and S. Solomon. Microscopic simulation of the stock market: The effect of microscopic diversity. *J. Phys. I France*, 5:1087–107, 1995.
- [29] W. Brian Arthur, John H. Holland, Blake LeBaron, Richard Palmer, and Paul Taylor. Asset pricing under endogenous expectations in an artificial stock market. In W. Brian Arthur, Steven N. Durlauf, and David A. Lane, editors, *The Economy as an Evolving Complex System II*. Addison-Wesley, 1997. <http://www.santafe.edu/sfi/publications/Working-Papers/96-12-093.ps>.
- [30] G. Caldarelli, M. Marsili, and Y.-C. Zhang. A prototype model of stock exchange. *Europhys. Lett.*, 40:479–84, 1997. arXiv:cond-mat/9709118.
- [31] R. Cont and J.-P. Bouchaud. Herd behavior and aggregate fluctuations in financial markets. arXiv:cond-mat/9712318, December 1997.
- [32] S. H. Chen, T. Lux, and M. Marchesi. Testing for non-linear structure in an artificial financial market. <http://www.ge.infm.it/econophysics/papers/lux/nonlin.zip>, 1998.
- [33] Christian Busshaus and Heiko Rieger. A prognosis oriented microscopic stock market model. *Physica A*, 267:443–52, 1999. arXiv:cond-mat/9903079.
- [34] Debashish Chowdhury and Dietrich Stauffer. A generalized spin model of financial markets. *Eur. Phys. J. B*, 8:477–82, 1999. arXiv:cond-mat/9810162.
- [35] Giulia Iori. A microsimulation of traders activity in the stock market: The role of heterogeneity, agents’ interactions and trade frictions. arXiv:adap-org/9905005, 1999.
- [36] Thomas Lux and Michele Marchesi. Scaling and criticality in a stochastic multi-agent model of a financial market. *Nature*, 397:498–500, 1999. <http://www.ge.infm.it/econophysics/papers/lux/lux-marchesi.ps.gz>.

- [37] John Von Neumann and Oskar Morgenstern. *Theory of games and economic behavior*. Princeton University Press, Princeton, 1944.
- [38] M. Marsili, S. Maslov, and Y.-C. Zhang. Dynamical optimization theory of a diversified portfolio. *Math. and Theor. Methods in Physics*, 7:403, 1998. arXiv:cond-mat/9801239.
- [39] John W. Pratt. Risk aversion in the small and the large. *Econometrica*, 32:122–136, 1964.
- [40] Haiping Fang and Liangyue Cao. Predicting and characterizing data sequences from structure-variable systems. *Phys. Rev. E*, 51:6254–7, 1995.
- [41] J. Doyne Farmer and J. J. Sidorowich. Predicting chaotic time series. *Phys. Rev. Lett.*, 59:845–8, 1987.
- [42] G. Sugihara and R. M. May. Nonlinear forecasting as a way of distinguishing chaos from measurement error in time series. *Nature*, 344:734–41, 1990.
- [43] M. Casdagli. Chaos and deterministic versus stochastic non-linear modelling. *J. R. Statist. Soc. B*, 54:303–28, 1991.
- [44] M. Paluš. Detecting nonlinearity in multivariate time series. arXiv:comp-gas/9507004, 1995.
- [45] M. Paluš, L. Pecen, and D. Pivka. Estimating predictability: Redundancy and surrogate data method. arXiv:comp-gas/9507003, 1995.
- [46] M. F. M. Osborne. Brownian motion in the stock market. *Operations Research*, 7:145–73, March–April 1959.
- [47] P. Bak, M. Paczuski, and M. Shubik. Price variations in a stock market with many agents. *Physica A*, 246:430–53, 1997. arXiv:cond-mat/9609144.
- [48] David Eliezer and Ian I. Kogan. Scaling laws for the market microstructure of the interdealer broker markets. arXiv:cond-mat/9808240, 1998.
- [49] B. A. Huberman and N. S. Glance. Evolutionary games and computer simulations. *Proc. Natl. Acad. Sci. USA*, 90:7716–8, 1993.
- [50] H. Bersini and V. Detours. Asynchrony induces stability in cellular automata based models. In R. A. Brooks and P. Maes, editors, *Artificial Life IV, Proceedings of the Fourth International Workshop on the Synthesis, and Simulation of Living Systems*, pages 382–7, Cambridge, 1994. MIT Press.

- [51] N. Rajewsky and M. Schreckenberg. Exact results for one-dimensional stochastic cellular automata with different types of updates. *Physica A*, 245:139–144, 1997. arXiv:cond-mat/9611154.
- [52] J. Rolf, T. Bohr, and M. H. Jensen. Directed percolation universality in asynchronous evolution of spatiotemporal intermittency. *Phys. Rev. E*, 57:R2503–6, 1998.
- [53] Sorin Solomon. Towards behaviorly realistic simulations of the stock market. arXiv:adap-org/9901003, 1999.
- [54] Barry G. Lawson and Steve Park. Asynchronous time evolution in an artificial society model. *J. Artificial Soc. and Social Sim.*, 3(1), 2000. <http://www.soc.surrey.ac.uk/JASSS/3/1/2.html>.
- [55] J. L. Kelly. A new interpretation of information rate. *Bell Syst. Tech. J.*, 35:917–26, 1956. <http://www.bjmath.com/bjmath/kelly/kelly.pdf>.
- [56] Robert C. Merton. *Continuous-Time Finance*. Blackwell, Cambridge, 1992.
- [57] S. Maslov and Y.-C. Zhang. Optimal investment strategy for risky assets. *Int. J. Theor. and Applied Finance*, 1(3):377, 1998. arXiv:cond-mat/9801240.
- [58] N. G. Van Kampen. *Stochastic Processes in Physics and Chemistry*. North-Holland, 1981.
- [59] J. Dooyne Farmer. Market force, ecology, and evolution. arXiv:adap-org/9812005, 1998.
- [60] New York Stock Exchange daily returns and volume, 1962–1988. Available from <http://www.stern.nyu.edu/~aweigend/Time-Series/Data/NYSE.Date.Day.Return.Volume.Vola>, provided by Blake LeBaron.
- [61] M. Plischke and Birger Bergersen. *Equilibrium Statistical Physics*. World Scientific, second edition, 1994.
- [62] R. Kohl. The influence of the number of different stocks on the Levy-Levy-Solomon model. *Int. J. Mod. Phys. C*, 8:1309–1316, 1997.
- [63] E. Egenter, T. Lux, and D. Stauffer. Finite-size effects in Monte Carlo simulations of two stock market models. *Physica A*, 268:250–6, 1999.
- [64] L. Bachelier. *Théorie de la spéculation*. PhD thesis, Ann. Sci. de l’Ecole Normale Supérieure, 1900.

- [65] Fischer Black and Myron Scholes. The pricing of options and corporate liabilities. *J. Political Economy*, 81:637–654, 1973.
- [66] Zoltán Palágyi and Rosario N. Mantegna. Empirical investigation of stock price dynamics in an emerging market. *Physica A*, 269:132–9, 1999.
- [67] J.-Ph. Bouchaud. Elements for a theory of financial risks. *Physica A*, 263:415–26, 1999.
- [68] Hari M. Gupta and José R. Campanha. The gradually truncated Lévy flight for systems with power law distributions. *Physica A*, 268:231–239, 1999.
- [69] Vasiliki Plerou, Parameswaran Gopikrishnan, Luís A. Nunes Amaral, Martin Meyer, and H. Eugene Stanley. Scaling of the distribution of price fluctuations of individual companies. *Phys. Rev. E*, 60:6519–29, 1999.
- [70] Ismo Koponen. Analytic approach to the problem of convergence of truncated Lévy flights towards the Gaussian stochastic process. *Phys. Rev. E*, 52:1197–9, 1995.
- [71] Rosario N. Mantegna and H. Eugene Stanley. Stochastic process with ultraslow convergence to a Gaussian: The truncated Lévy flight. *Phys. Rev. Lett.*, 73:2946–9, 1994.
- [72] Hendrik J. Blok and Birger Bergersen. Effect of boundary conditions on scaling in the “game of Life”. *Phys. Rev. E*, 55:6249–52, 1997. <http://rikblok.cjb.net/lib/blok97.html>.
- [73] Yahoo! Finance historical quotes, 1999. <http://chart.yahoo.com/t>.
- [74] Peter K. Clark. A subordinated stochastic process model with finite variance for speculative prices. *Econometrica*, 41:135–55, 1973.
- [75] Yi-Cheng Zhang. Toward a theory of marginally efficient markets. arXiv:cond-mat/9901243, 1999.
- [76] Andrew W. Lo. Long-term memory in stock market prices. *Econometrica*, 59:1279–1313, 1991.
- [77] Pierre Cizeau, Yanhui Liu, Martin Meyer, C.-K. Peng, and H. Eugene Stanley. Volatility distribution in the S&P500 stock index. *Physica A*, 245:441–5, 1997.
- [78] Yanhui Liu, Pierre Cizeau, Martin Meyer, C.-K. Peng, and H. Eugene Stanley. Correlations in economic time series. *Physica A*, 245:437–40, 1997.

- [79] J. Rotyis and G. Vattay. Statistical analysis of the stock index of the budapest stock exchange. arXiv:cond-mat/9711008, 1997.
- [80] A. Arnéodo, J.-F. Muzy, and D. Sornette. “Direct” causal cascade in the stock market. *Eur. Phys. J. B*, 2:277–282, 1998.
- [81] Rosario N. Mantegna, Zoltán Palágyi, and H. Eugene Stanley. Applications of statistical mechanics to finance. *Physica A*, 274:216–221, 1999.
- [82] Hans E. Schepers, Johannes H. G. M. Van Beek, and James B. Basingthwaight. Four methods to estimate the fractal dimension from self-affine signals. *IEEE Engineering in Medicine and Biology*, 11:57–64, 1992.
- [83] E. W. Montroll and M. F. Shlesinger. Maximum entropy formalism, fractals, scaling phenomena, and $1/f$ noise: A tale of tails. *J. Stat. Phys.*, 32(2):209–30, 1983.
- [84] Anders Johansen and Didier Sornette. The Nasdaq crash of April 2000: Yet another example of log-periodicity in a speculative bubble ending in a crash. arXiv:cond-mat/0004263, 2000.
- [85] Sergei Maslov and Yi-Cheng Zhang. Probability distribution of drawdowns in risky investments. *Physica A*, 262:232–41, 1999. arXiv:cond-mat/9808295.
- [86] H. Saleur, C. G. Sammis, and D. Sornette. Discrete scale invariance, complex fractal dimensions, and log-periodic fluctuations in seismicity. *J. Geophys. Research*, 101:17661–77, 1996.
- [87] Didier Sornette. Discrete scale invariance and complex dimensions. *Physics Reports*, 297:239–270, 1998. arXiv:cond-mat/9707012.
- [88] P. Bak and M. Paczuski. Why nature is complex. *Physics World*, pages 39–43, December 1993.
- [89] Daniel Groleau. *Study of the Scaling and Temporal Properties of a Simplified Earthquake Model*. PhD thesis, University of British Columbia, 1997.
- [90] D. Sornette and C. G. Sammis. Complex critical exponents from renormalization group theory of earthquakes: Implications for earthquake predictions. *J. Phys. I France*, 5:607–19, 1995.
- [91] Anders Johansen, Didier Sornette, Hiroshi Wakita, Urumu Tsunogai, William L. Newman, and Hubert Saleur. Discrete scaling in earthquake precursory phenomena: Evidence in the kobe earthquake, japan. *J. Phys. I France*, 6:1391–402, 1996.

- [92] Anders Johansen, Didier Sornette, and Olivier Ledoit. Predicting financial crashes using discrete scale invariance. *J. Risk*, 1(4):5–32, 1999. arXiv:cond-mat/9903321.
- [93] Laurent Laloux, Marc Potters, Rama Cont, Jean-Pierre Aguilar, and Jean-Philippe Bouchaud. Are financial crashes predictable? arXiv:cond-mat/9804111, 1998.
- [94] L. S. Lasdon, A. D. Waren, A. Jain, and M. Ratner. Design and testing of a generalized reduced gradient code for nonlinear programming. *ACM Trans. on Math. Software*, 4:34–50, 1978.
- [95] Per Bak. *How Nature works: The science of self-organized criticality*. Springer-Verlag, New York, 1996.
- [96] D. Stauffer and T.J.P. Penna. Crossover in the Cont-Bouchaud percolation model for market fluctuations. *Physica A*, 256:284–90, 1998.
- [97] Iksoo Chang and Dietrich Stauffer. Fundamental judgement in Cont-Bouchaud herding model of market fluctuations. *Physica A*, 264:294–8, 1999.
- [98] Víctor M. Eguíluz and Martín G. Zimmermann. Dispersion of rumors and herd behavior. arXiv:cond-mat/9908069, 1999.
- [99] Dietrich Stauffer and Didier Sornette. Self-organized percolation model for stock market fluctuations. *Physica A*, 271:496–506, 1999.
- [100] Lei-Han Tang and Guang-Shan Tian. Reaction-diffusion-branching models of stock price fluctuations. *Physica A*, 264:543–50, 1999.
- [101] R. D’Hulst and G. J. Rodgers. Exact solution of a model for crowding and information transmission in financial markets. arXiv:cond-mat/9908481, 1999.
- [102] B. M. Roehner and D. Sornette. The sharp peak-flat trough pattern and critical speculation. *Eur. Phys. J. B*, 4:387–399, 1998.
- [103] Benoit B. Mandelbrot and John W. Van Ness. Fractional Brownian motions, fractional noises and applications. *SIAM Review*, 10:422–37, 1968.
- [104] Benoit B. Mandelbrot. A fast fractional Gaussian noise generator. *Water Resources Research*, 7:543–53, 1971.
- [105] Murad S. Taqqu, Vadim Teverovsky, and Walter Willinger. Estimators for long-range dependence: An empirical study. *Fractals*, 3:785–788, 1995.

- [106] Sandro Rambaldi and Ombretta Pinazza. An accurate fractional Brownian motion generator. *Physica A*, 208:21–30, 1994.
- [107] Z.-M. Yin. New methods for simulation of fractional Brownian motion. *Journal of Computational Physics*, 127:66–72, 1996.
- [108] James B. Bassingthwaighte and Gary M. Raymond. Evaluating rescaled range analysis for time series. *Annals of Biomedical Engineering*, 22:432–44, 1994.
- [109] Gary M. Raymond and James B. Bassingthwaighte. Deriving dispersional and scaled windowed variance analyses using the correlation function of discrete fractional Gaussian noise. *Physica A*, 265:85–96, 1999.
- [110] Berndt Pilgram and Daniel T. Kaplan. A comparison of estimators for $1/f$ noise. *Physica D*, 114:108–122, 1998.
- [111] B. Mandelbrot. *The Fractal Geometry of Nature*. Freeman, 1983.
- [112] Oscar J. Mesa and German Poveda. The Hurst effect: The scale of fluctuation approach. *Water Resources Research*, 29:3995–4002, 1993.
- [113] Philippe Carmona and Laure Coutin. Fractional Brownian motion and the Markov property. arXiv:math.PR/9809123, 1998.
- [114] R. F. Voss. Random fractal forgeries. In R. A. Earnshaw, editor, *Fundamental Algorithms in Computer Graphics*, pages 805–835. Springer-Verlag, Berlin, 1985.
- [115] Vern Paxson. Fast, approximate synthesis of fractional Gaussian noise for generating self-similar network traffic. *Computer Communications Review*, 27(5):5–18, 1997.
- [116] Y. G. Sinai. Self-similar probability distributions. *Theory of Probability and its Applications*, 21:64–80, 1976.
- [117] James B. Bassingthwaighte and Gary M. Raymond. Evaluation of the dispersional analysis method for fractal time series. *Annals of Biomedical Engineering*, 23:491–505, 1995.
- [118] David C. Caccia, Donald Percival, Michael J. Cannon, Gary Raymond, and James B. Bassingthwaighte. Analyzing exact fractal time series: Evaluating dispersional analysis and rescaled range analysis. *Physica A*, 246:609–632, 1997.

- [119] H. E. Hurst. Long-term storage capacity of reservoirs. *Trans. Am. Soc. Civ. Eng.*, 116:770–808, 1951.
- [120] Jens Feder. *Fractals*. Plenum, New York, 1988.
- [121] Yanqing Chen, Mingzhou Ding, and J. A. Scott Kelso. Long memory processes ($1/f^\alpha$ type) in human coordination. *Phys. Rev. Lett.*, 79:4501–4504, 1997.
- [122] Larry S. Liebovitch and Weiming Yang. Transition from persistent to antipersistent correlation in biological systems. *Phys. Rev. E*, 56:4557–4566, 1997.
- [123] R. Oliver and J. L. Ballester. Is there memory in solar activity? *Phys. Rev. E*, 58:5650–5654, 1998.
- [124] Murad S. Taqqu and Vadim Teverovsky. Robustness of Whittle-type estimators for time series with long-range dependence. *Stochastic Models*, 13:723–757, 1997. <http://math.bu.edu/INDIVIDUAL/murad/pub/robustness-posted.ps>.
- [125] Michael J. Cannon, Donald B. Percival, David C. Caccia, Gary M. Raymond, and James B. Bassingthwaighte. Evaluating scaled window variance methods for estimating the Hurst coefficient of time series. *Physica A*, 241:606–26, 1997.
- [126] C.-K. Peng, S. V. Buldyrev, S. Havlin, M. Simons, H. E. Stanley, and A. L. Goldberger. Mosaic organization of DNA nucleotides. *Phys. Rev. E*, 49:1685–1689, 1994.
- [127] Elliott W. Montroll and Bruce J. West. On an enriched collection of stochastic processes. In E. W. Montroll and J. L. Lebowitz, editors, *Fluctuation Phenomena*, pages 61–206. North-Holland, Amsterdam, 1987.
- [128] Rafał Weron. On the Chambers-Mallows-Stuck method for simulating skewed stable random variables (and correction). *Statistical Probability Letters*, 28:165–171, 1996. <http://www.im.pwr.wroc.pl/~hugo/pub1/RWeron-SPL-95.ps>, correction in Research Report HSC/96/1, Wroclaw Univ. of Technology [rweron-spl95-corr.ps](http://www.im.pwr.wroc.pl/~hugo/pub1/RWeron-SPL-95-correction.ps).
- [129] Stephen M. Kogon and Dimitris G. Manolakis. Signal modeling with self-similar α -stable processes: The fractional Lévy stable motion model. *IEEE Trans. on Signal Processing*, 44:1006–1010, 1996.