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Econophysics: A challenge to econometricians

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HIGHLIGHTS

- Presents an econophysics alternative to mainstream econometric models.
- Using entropy analysis demonstrates how the main assumption used commonly in mainstream econometrics is violated on small time scales.
- Models short-term fluctuations in the foreign exchange markets using an adapted Ising spin model.
- Shows how to build high-frequency foreign exchange trading models based on econophysics.

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ABSTRACT

The study contrasts mainstream economics – operating on time scales of hours and days – with behavioural finance, econophysics and high-frequency trading, more applicable to short-term time scales of the order of minutes and seconds. We show how the central theoretical assumption underpinning prevailing economic theories is violated on small time scales. We also demonstrate how an alternative behavioural econophysics can model reactions of market participants to short-term movements in foreign exchange markets and, in a direct contradiction of the orthodox economics, design a rudimentary IsingFX automated trading system.

By replacing costly human forex dealers with banks of Field-Programmable Gate Array (FPGA) devices that implement in hardware high-frequency behavioural trading models of the type described here, brokerages and forex liquidity providers can expect to gain significant reductions in operating costs.

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1. Introduction

The orthodox econometrics as well as the Random Walk Hypothesis (itself consistent with the Efficient Markets Hypothesis built upon Rational Expectations) treat logarithmic financial returns as a collection of i.i.d. (independently and identically distributed) random variables [1], which simplifies the use of statistical methods in finance. In essence, modern finance assumes that financial time series are random, investors make rational decisions and active short-term trading (as opposed to passive buy-and-hold investing) is referred to as futile "noise trading" [2]. In a perfect world this might well be true. However, back in the "real world" humans often act irrationally and, consequently, the i.i.d. assumption underpinning rational econometric models may not necessarily hold true. The irrationality of human behaviour is simply averaged out

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from mainstream economics and econometrics. Due to its inability to model erratic human behaviour, over the long run econometrics conveniently averages out irrationality from existence [3]. As once stated by the famous economist John Maynard Keynes, "in the long run we are all dead" [4], yet the readers of this article are most certainly alive. Similarly, extreme events and crashes still happen, and will keep coming with regularity for the foreseeable future since human nature never changes. Indeed, financial markets are driven by crowd behaviour, by fear and greed of irrational short-term traders, in other words by subjective psychological phenomena. Statistical testing whether or not financial markets are efficient is often obscured by making these tests conditional upon not necessarily correct parametric regression models, as has been made clear in Refs. [5,6]. The inability of mainstream economists to anticipate short-term fluctuations of financial markets stands behind the recent rise in prominence [7] of the alternative behavioural finance, evidenced by the 2013 Nobel Memorial Prize in Economics co-awarded to the behavioural economist Robert J. Shiller. (In an interesting twist of fate, in 2013 the Nobel Memorial Prize was also awarded to Eugene F. Fama and Lars Peter Hansen, proponents of the mainstream econometrics which competes directly with behavioural finance. This only goes to show how difficult it is to form consensus on major issues in economics.) Since psychology as well as behavioural finance both belong to the category of soft social sciences, they may not necessarily offer ready-to-use mathematical tools for building financial trading systems on top of them. Instead, their subjective findings need to be translated into objective trading rules, intended to execute automatically on computers without human interference. Statistical physics, and econophysics [8–11] in particular may offer some models and tools for expressing in quantitative ways subjective human behaviour.

Human irrationality manifests itself in many ways. One effect acknowledged by the mainstream theoretical economists as well as practitioners is collective herding behaviour of traders. Using existing entropy analysis, in this article we reveal evidence of systematic violations of the i.i.d. assumption. It is often said that extraordinary claims require extraordinary evidence. Subsequently we also demonstrate how to build realistic foreign exchange trading systems based upon the idea of herding behaviour, as enforced through the use of the Ising spin model, common in statistical physics, and adapted to the financial domain by the author. The idea of applying the Ising model to financial markets or social phenomena is not new [12,13]. The large body of existing econophysics literature, reviewed in for example Ref. [12], tends to focus on running artificial agent-based simulations with realistic supply/demand-based artificial price formation mechanisms, in order to reproduce so-called "stylised facts" (volatility clustering, fat tails etc.). In contrast, the IsingFX model described in this paper does not include any price formation mechanism. Nor is it used to generate any artificial price time series, to be compared against the dynamics of a real market. Instead the spins (artificial traders) within the IsingFX model react to real forex prices streamed in real-time using a C/C++ FIX API connection to the author's foreign exchange trading account. As the output of the real-prices-driven IsingFX, the net lattice magnetisation is translated into BUY/SELL trading decisions, ready to be transmitted to the forex market using the FIX protocol (an industry standard).

2. Entropy analysis

Approximate Entropy (ApEn), being "a model independent measure of sequential irregularity" [14], has been employed in this study to demonstrate beyond reasonable doubt that high frequency foreign exchange time series do exhibit certain sequential regularities incompatible with the i.i.d. assumption made by mainstream econometricians [1]. A recent application of ApEn to study speculative bubbles conditions in Tunisian and French stock markets can be found in Ref. [15]. Itself non-parametric, Approximate Entropy is also capable [16] of either endorsing or rejecting parametric econometric models such as ARIMA or GARCH [1].

Tick data collected from the foreign exchange market during the three-week period between 10th and 29th March 2014 are used to construct time series of logarithmic returns $\log s_t - \log s_{t-1}$ for ten selected currency pairs, where s_t are middle prices between bid and ask quotes. Employing a sliding window of the length $N = 129$, let us assume a logarithmic returns sequence $\{x_i\}$, $i = 1 \ldots N$. The value of Approximate Entropy $ApEn(m, r, N)$ for a particular sequence (sliding window) is calculated using the following parameters: $m = 2$ and $r = 0.4 \times mad$, where mad denotes a mean absolute deviation of $\{x_{i+1} - x_i\}$ (robustness to outliers), as opposed to the standard deviation used in the original Approximate Entropy measure [14,16]. Based on the sequence $\{x_i\}$, delay vectors of the length m are constructed: the ith delay vector $\mathbf{x}(i) = [x_i, x_{i+1}, \ldots, x_{i+m-1}]$ and the jth delay vector $\mathbf{x}(j) = \left[x_j, x_{j+1}, \ldots, x_{j+m-1}\right]$. Let us define a quantity $C_i^m(r)$ to be

$$C_i^m(r) = \Big(\text{the number of } \mathbf{x}(j) \text{ such that distance } (\mathbf{x}(i), \mathbf{x}(j)) < r\Big)/(N - m + 1)$$

with the distance measure such that distance $(\mathbf{a}, \mathbf{b}) = \max_{k=1\ldots m} |\mathbf{a}_k - \mathbf{b}_k|$ and distance $(\mathbf{x}(i), \mathbf{x}(i)) = 0$. Then Approximate Entropy for the sequence $\{x_i\}$ is defined to be

$$ApEn(m, r, N) = \Phi^m(r) - \Phi^{m+1}(r)$$

where $\Phi^m(r) = (N - m + 1)^{-1} \sum_{i=1}^{N-m+1} \log C_i^m(r)$.

In the world of algorithmic high frequency trading three weeks is more than enough to "make or break" an algorithm. Each logarithmic returns time series contains over one million price ticks coming at time intervals ranging from sub-second to few seconds, depending on the time of the day. Fig. 1 shows an experimental implementation of the algorithm to compute the Approximate Entropy using Xilinx Field-Programmable Gate Array (FPGA) technology. The real reason for making an extra effort to implement ApEn in hardware was to practise bit-level digital hardware design in VHDL (VHSIC

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