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Self-organized criticality and stock market dynamics: an empirical study

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Abstract

The stock market is a complex self-interacting system, characterized by intermittent behaviour. Periods of high activity alternate with periods of relative calm. In the present work we investigate empirically the possibility that the market is in a self-organized critical state (SOC). A wavelet transform method is used in order to separate high activity periods, related to the avalanches found in sandpile models, from quiescent. A statistical analysis of the filtered data shows a power law behaviour in the avalanche size, duration and laminar times. The memory process, implied by the power law distribution of the laminar times, is not consistent with classical conservative models for self-organized criticality. We argue that a "near-SOC" state or a time dependence in the driver, which may be chaotic, can explain this behaviour.

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1. Introduction

Since the publication of the articles of Bak, Tang and Wiesenfeld (BTW) [1], the concept of self-organized criticality (SOC) has been invoked to explain the

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dynamical behaviour of many complex systems, from physics to biology and the social sciences [2,3]. The key concept of SOC is that complex systems, that is systems constituted by many interacting elements, although obeying different microscopic physics, may exhibit similar dynamical behaviour. In particular, the statistical properties of these systems can be described by power laws, reflecting a lack of any characteristic scale. These features are equivalent to those of physical systems during a phase transition, that is at the critical point. It is worth emphasizing that the original idea [1] was that the critical state was reached "naturally", without any external tuning. This is the origin of the adjective *self*-organized. In reality a certain degree of tuning is necessary: implicit tunings like local conservation laws and specific boundary conditions seem to be important ingredients for the appearance of power laws [2].

The classical example of a system exhibiting SOC behaviour is the 2D sandpile model [1–3]. Here the cells of a grid are randomly filled, by an external random driver, with "sand". When the gradient between two adjacent cells exceeds a certain threshold a redistribution of the sand occurs, leading to more instabilities and further redistributions. The benchmark of this system, indeed of all systems exhibiting SOC, is that the distribution of the avalanche sizes, their duration and the energy released, obey power laws.

The framework of self-organized criticality has been claimed to play an important role in solar flaring [4], space plasmas [5] and earthquakes [6] in the context of both astrophysics and geophysics. In the biological sciences, SOC, has been related, for example, with biodiversity and evolution/extinction [7]. Some work has also been carried out in the social sciences. In particular, traffic flow and traffic jams [8], wars [9] and stock-market [3,10–12] dynamics have been studied. A more detailed list of subjects and references related to SOC can be found in the review paper of Turcotte [3].

In the present work we will provide empirical evidence for connections between self-organized criticality and the stock market, considered as a complex system constituted of many interacting individuals. We analyze the tick-by-tick behaviour of the Nasdaq100 index, $P(t)$, from 21/6/1999 to 19/6/2002 for a total of 2^{19} data. A sample of this data is illustrated in Fig. 1(a). In particular, we study the logarithmic returns of this index, which are defined as $R(t) = \ln(P(t+1)) - \ln(P(t))$ and plotted in Fig. 1(b).

To examine the extent to which our findings apply to other stock market indices we also studied the S&P ASX50 (for the Australian stock market) at intervals of 30 min over the period 20/1/1998 to 1/5/2002, for a total of 2^{14} data points. Possible differences between daily and high-frequency data have also been taken into consideration though the analysis of the Dow Jones daily closures from 2/2/1939 to 13/4/2004. The results are presented in Section 3.

From a visual analysis of the time series of returns, Fig. 1(b), we observe long periods of relative tranquility, characterized by small fluctuations, and periods in which the index goes through very large fluctuations, equivalent to avalanches, clustered in relatively short time intervals. These may be viewed as a consequence of a build-up process leading the system to an extremely unstable state. Once this