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Fractal properties of financial markets

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HIGHLIGHTS

- Analysis of the S&P 500 index using a simple fractal function is proposed.
- The Besicovitch–Ursell function is fitted to the data for several financial growths.
- The fitting function reproduces complete financial growths in a natural way.
- Shortening the fitting interval causes deviations between the two curves.
- Fractal functions have great modeling abilities concerning market dynamics.

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ABSTRACT

We present an analysis of the USA stock market using a simple fractal function. Financial bubbles preceding the 1987, 2000 and 2007 crashes are investigated using the Besicovitch–Ursell fractal function. Fits show a good agreement with the S&P 500 data when a complete financial growth is considered, starting at the threshold of the abrupt growth and ending at the peak. Moving the final time of the fitting interval towards earlier dates causes growing discrepancy between two curves. On the basis of a detailed analysis of the financial index behavior we propose a method for identifying the stage of the current financial growth and estimating the time in which the index value is going to reach the maximum.

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1. Introduction

Events such as earthquakes, financial crashes, material breaking, etc., are ubiquitous in nature. Describing them and finding tools for their prediction is a subject of great interest. Complex systems can generate large fluctuations and unpredictable outcomes, while at the same time they exhibit some general features that can be studied. One of the main tasks of statistical physics is finding the laws describing fluctuations. Recently, a lot of effort has been made in modeling and analyzing financial market dynamics using concepts and tools of statistical physics [1–9].

Scaling phenomena, characteristic of the systems that exhibit self-organized criticality, are observed also in financial markets. Analyzing the S&P 500 index, scaling behavior was observed for time intervals spanning three orders of magnitude—from 1 to 1000 min [4]. The probability distribution of the index variations was found to be non-Gaussian. One of the important characteristics of financial time series is a non-negligible probability of the occurrence of large market fluctuations—during the 1987 stock market crash the daily move of the S&P 500 index recorded a magnitude of about 20 standard deviations. Stock returns display tails that are much more pronounced than a simple Gaussian [10,11].

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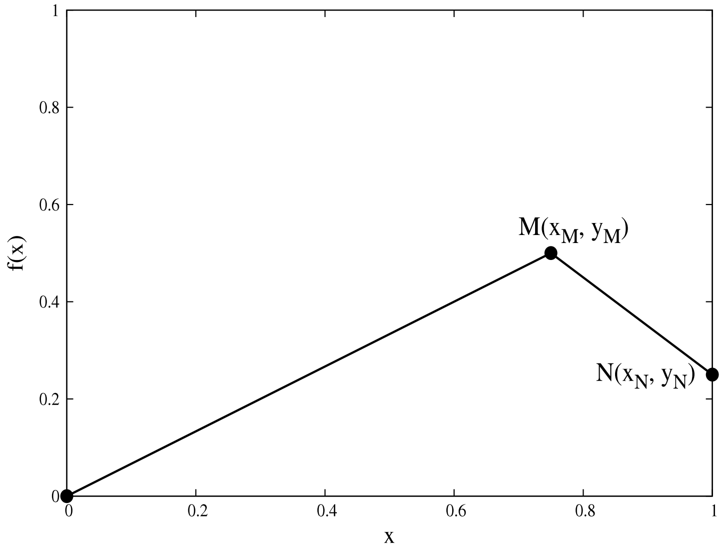

Fig. 1. Model function $f(x)$ (Eq. (1)) with $x_M = 0.75,\ y_M = 0.50,\ x_N = 1.0,\ y_N = 0.25$.

Table 1
Values of the fitting parameters obtained by fitting the B–U function to S&P 500 data for the financial growths ending in 1987, 2000 and 2007. The last column contains the r.m.s. errors of the fits.

Year	x_M	y_M	y_N	p_c	s_0	*r.m.s.*
1987	0.81528	0.12175	0.61857	1.9108	0.69802	0.0215
2000	0.91932	0.09926	0.32264	1.9045	0.48805	0.0400
2007	0.89584	0.30109	0.49857	1.8183	0.50153	0.0337

Possibility of identifying financial crises and predicting financial crashes has been analyzed in many papers [12–18]. Financial markets are nonlinear, complex systems described by enormous number of mostly unknown parameters. There are two main philosophies in applying tools of statistical physics to describe various financial events including crashes.

The first one is a global approach and its aim is to observe well defined structures in financial time series preceding the crash. One of the properties of a financial bubble is the faster-than-exponential growth of the price [16]. Each burst of super-exponential price growth is followed by a crash, i.e. the average exponential growth of the index consists of a succession of bubbles and crashes, which seem to be the norm rather than the exception. Price growth can be modeled by the so-called log-periodic power law (LPPL) [14,15]. Fitting the financial data by the log-periodic function can determine the critical time for a possible "phase transition" or crash. The end of a bubble is not necessarily accompanied by a crash, but the corresponding critical time is the time where the crash is the most probable [19]. Crashes can occur before, or a bubble can land smoothly, therefore, only probabilistic forecasts can be developed.

The other approach is to study the local scaling properties of financial time series and investigate the long-memory correlations [20–22]. It is known that the Hurst exponent measures the level of persistency in the given signal. The value $H = 0.5$ corresponds to the "Markovian" behavior and the absence of long-term correlations. For $H > 0.5$ there is a persistence, and for $H < 0.5$ antipersistence in the time series. When the trend in the market is strong and well determined one should observe some long-range correlations in returns and consequently higher values of the Hurst exponent. Contrary, at the index maximum the increasing trend is broken and the decreasing one is set and before the crash the signal of anti-correlation and the drop of the Hurst exponent appear.

Fractal market hypothesis is tightly connected to multifractality and long-range dependence in financial time series. Financial markets are considered as complex systems consisting of many heterogeneous agents which are distinguishable mainly with respect to their investment horizons. These horizons range from seconds (market makers) up to several years (pension funds). Each of the investors group has its own trading rules and strategies. It was found [22,23] that the turbulent times are characterized by the dominance of short investment horizons.

Self-similarity in financial price records manifests itself in the virtual impossibility to distinguish the price records on different time scales, when the axes are not labeled [24]. This leads to the idea to describe the oscillations in financial markets by fractal functions [25]. Here we demonstrate that financial growth can be successfully modeled by a simple fractal function. We provide the fits to real financial data. On the basis of the well known S&P 500 index we analyze financial growths preceding the 1987, 2000 and 2007 crashes. We also analyze the current financial growth, starting from the minimal value reached during the last economic crisis.

Although having different triggers, the mentioned crises display similar behavior. Some economists think that a crash may be a result of social interactions and that the crashes have fundamentally similar origins that should be found in

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