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Complexity and multifractal behaviors of multiscale-continuum percolation financial system for Chinese stock markets

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HIGHLIGHTS

- New agent-based financial dynamics is developed by multiscale-continuum percolation.
- MCSE is used to measure the degree of asynchrony of return autocorrelation series.
- The complexity of returns of the model is investigated by the MSE analysis.
- Nonlinear complexity and multifractal features of returns are demonstrated.
- Empirical research shows the rationality of the proposed model for financial dynamics.

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ABSTRACT

A new financial agent-based time series model is developed and investigated by multiscale-continuum percolation system, which can be viewed as an extended version of continuum percolation system. In this financial model, for different parameters of proportion and density, two Poisson point processes (where the radii of points represent the ability of receiving or transmitting information among investors) are applied to model a random stock price process, in an attempt to investigate the fluctuation dynamics of the financial market. To validate its effectiveness and rationality, we compare the statistical behaviors and the multifractal behaviors of the simulated data derived from the proposed model with those of the real stock markets. Further, the multiscale sample entropy analysis is employed to study the complexity of the returns, and the cross-sample entropy analysis is applied to measure the degree of asynchrony of return autocorrelation time series. The empirical results indicate that the proposed financial model can simulate and reproduce some significant characteristics of the real stock markets to a certain extent.

1. Introduction

Recently, there has been significant interest in the investigation of financial complex systems, since it becomes more important to find the inside principles of the complex systems, or more accurately, answer the origination of the change of the systems. Many models in the field of statistical physics (or interacting particle systems) are applied in the simulation of financial market dynamics, which are based on the perspective that the price movements are caused primarily by the arrival of new information and herding effect [1–3], like Ising dynamic system [4], agent-based models [5–8], epidemic

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system [9], interacting voter particle system [10], continuum percolation [11]. While the empirical results of stock returns provide various empirical evidence, that has challenged the old random-walk hypothesis [12], requiring the invention of new financial models to describe price movements in the markets. A series of crucial statistical behaviors, such as fat-tail distribution of price changes [13–15], volatility clustering [16], long-term memory [17] and multifractality of volatilities [4,18–20], are uncovered from empirical and theoretical research by the previous studies. Stauffer and Penna [21] developed a price model by the two-dimensional lattice percolation system, the local interaction or influence among traders in a stock market is constructed, and a cluster of percolation is applied to define the cluster of traders sharing the same opinion about the market. They suppose that the spread of information leads to the stock price fluctuation, and when the influence rate of the model is around or at a critical value, the existence of fat-tail behavior for the returns is clearly observed. The critical phenomena of percolation model is used to illustrate the herd behavior of stock market participants. Xiao and Wang [11] introduced an interacting-agent model of speculative activity explaining price formation which is based on the continuum percolation. The empirical study showed that the established financial model can reproduce the main factors and reveal important statistical characteristics of asset returns.

The objective of this work is to give an approach in revealing the features behind the financial market. The proposed price dynamics of the present work is based on the multiscale-continuum percolation system. The multiscale-continuum percolation (corresponding to Poisson points with different radii), which can be viewed as an extended version of the continuum percolation, is more reasonable in the financial dynamics modeling. In this financial model, the local interaction or influence among traders is developed by the multiscale-continuum percolation, and a cluster in multiscale-continuum percolation is developed to imitate a clustering of traders with the same view of the market. In fact, there are different types of investors in stock markets, so for simplicity, we use two kinds of Poisson points to study the influence on fluctuations by setting different proportions (γ) of two radii, where the radius represents the ability of transmitting information. The related work may reasonably and vividly explain the fluctuations caused by the change of the constitution of investors, and it also expands the concept of modeling in the financial research. Further, for different proportions and densities of the model, we investigate the fluctuate behaviors of return series of the model by multiscale sample entropy analysis [22,23], multiscale cross-sample entropy analysis [24,25] and multifractal detrended fluctuation analysis [26–28].

2. Description of multiscale-continuum percolation

The continuum percolation system has been applied to model many phenomena (which are made up of individual events that overlap, for example, the way individual raindrops eventually make the ground evenly wet) in geology, chemistry, biology, and physics, such as the study of porous material and semiconductors. We now give a brief description of multiscale-continuum percolation theory, which is the extended version of the Poisson blob model or the Boolean model in stochastic geometry, and it is a process of liquid leaks between different sites, for more details about percolation theory see [29–34].

In the following, we use the multiscale-continuum percolation theory to simulate the financial market. There are two illustrations of the continuum percolation and the multiscale-particle continuum percolation in a finite rectangle $[-l, l]^2$ in Fig. 1. Fig. 1(a) is a map of traditional continuum percolation, there only exists one kind of particles with same radius, and it can be seen that there is a cluster of spheres nearest to the origin. Fig. 1(b) is an illustration of multi-continuum percolation system, there are two kinds of particles with different radii. In the financial model of this paper, these particles represent the investors in the financial market, and suppose that the investors at one cluster of spheres hold the same attitude towards the market. Since the stock market has progressed rapidly, there are more than one kind of investors actively in the market. So we use two kinds of particles with different radii ρ_1 and ρ_2 ($\rho_1 > \rho_2$), where the radius is equivalent to the visual range of investors in the financial system. Particles with small radii (ρ_2) represent the individual investors. Particles with large radii (ρ_1) represent the institutional investors, who always have stronger ability to get information and influence others. We use $X(A)$ to represent the number of random points inside A, where A belongs to Euclidean space. The point process X is a homogeneous Poisson process with the density of $\lambda(> 0)$ [29,30,35]. Considering each point X_i ($i = 1, 2, \ldots$) as the center, we place a sphere of radius ρ_1 or ρ_2 (with the probability γ or $1 - \gamma$ respectively), where γ represents the proportion of Poisson points with radius ρ_1 in the system. The corresponding sphere is denoted by P_i. If $P_i \cap P_j \neq \emptyset$, two spheres P_i and P_j are called adjacent, if there exists a sequence $P_{i_1}, P_{i_2}, \ldots, P_{i_k}$ of spheres such that $P_{i_1} = P_i$ and $P_{i_k} = P_j$ and P_{i_q} is adjacent to P_{i_q+1} for $1 \le q \le k$, then we write $P_i \leftrightarrow P_j$. We suppose that particles are overlapped when the sum of their radii is smaller than their distance, and this means that they will hold the same attitude on the basis of herding effect, and the information can be spreading. We called these overlapped particles "neighbors". A cluster of spheres is a set $\{P_i : i \in \mathcal{J}\}$ of spheres which is maximal with the connection $P_i \leftrightarrow P_j$ for all $i, j \in \mathcal{J}$. We use $C(X_i)$ to represent a cluster of spheres containing P_i, while $|C(X_i)|$ denotes the number of spheres belonging to it. $C(X_i)$ is the cluster that shares the same investment attitude, for more details see [21,35–38].

3. Financial continuum percolation system

In this section, a financial price dynamics and the corresponding return process are developed by the two-dimensional multiscale-continuum percolation system, where the ability of receiving or transmitting information among investors is a crucial factor in the real stock market [3,39]. We suppose that the volatilities of stock prices are responded to the spreading