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Nonlinear complexity of random visibility graph and Lempel-Ziv on multitype range-intensity interacting financial dynamics

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HIGHLIGHTS

- A new financial price model is developed based on multitype range-intensity contact system.
- Random visibility graph is firstly proposed to investigate nonlinear complex behavior of stock markets.
- Lempel-Ziv complexity is adopted to study complexity behaviors of different shuffled returns.
- Empirical results show the rationality of proposed financial model and random visibility graph method.

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ABSTRACT

In an attempt to investigate the nonlinear complex evolution of financial dynamics, a new financial price model — the multitype range-intensity contact (MRIC) financial model, is developed based on the multitype range-intensity interacting contact system, in which the interaction and transmission of different types of investment attitudes in a stock market are simulated by viruses spreading. Two new random visibility graph (VG) based analyses and Lempel-Ziv complexity (LZC) are applied to study the complex behaviors of return time series and the corresponding random sorted series. The VG method is the complex network theory, and the LZC is a non-parametric measure of complexity reflecting the rate of new pattern generation of a series. In this work, the real stock market indices are considered to be comparatively studied with the simulation data of the proposed model. Further, the numerical empirical study shows the similar complexity behaviors between the model and the real markets, the research confirms that the financial model is reasonable to some extent.

1. Introduction

Recently, the analysis of financial dynamics based on stochastic dynamical systems has become one of significant research topics in financial research. The modeling of dynamics of forward prices is becoming a key problem in the risk management, physical assets valuation, and derivatives pricing. Previous study of fluctuations of financial prices has demonstrated some important statistical behaviors (or stylized facts [1]), such as heavy tails distribution of price changes [2], power-law of logarithmic returns and volume [3–9], multi-fractality of volatility [10–12] and so on [13–30]. In an attempt to explain some of these stylized facts, various models have been introduced [24,28,30–34]. Some of these methods come from the

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field of statistical physics systems or interacting particle systems [24,28,33–35]. Stanley et al. [21] put forward that economic systems such as financial markets are similar to physical systems in that they are comprised of a large number of interacting agents. These economic agents are "thinking" units and they interact in complicated ways. Lux [20] mentioned that financial prices have been found to exhibit some universal characteristics that resemble the scaling laws characterizing physical systems in which large numbers of units interact. Krawiecki [16] and Fang and Wang [10] developed an interacting-agent model of speculative activity explaining price formation in financial market that is based on the stochastic Ising dynamic system. The Ising model is the part of the common culture of physics as the simplest representation of interacting elements with a finite number of possible states, and Ref. [36] reviews how the Ising model of phase transitions has developed to model social and financial systems. Moreover, the paper works on the stock market model and compares with Shanghai Stock Exchange (SSE) Composite Index and Shenzhen Stock Exchange (SZSE) Component Index, since SSE and SZSE indexes are two representative stock indexes in China. The SSE is an order-driven market, there are some order-driven models [37], and some papers on the order-driven models are based on the Chinese stock market data, see Refs. [1,38–40].

In the present work, the stochastic multitype range-intensity contact (MRIC) process is proposed to develop a random agent-based financial price model. The stochastic contact process is a model for epidemic spreading in a continuous time Markov process [41–44]. The multitype range-intensity contact process is an extended process from the contact process. There are two types of particles, which can be interpreted as a model for the spreading of two kinds of diseases, one is heavy and the other is slight. They spread different range with different intensity, proportional to the number of heavily and slightly infected neighbors, respectively, and both types of infected individuals could be recovered at a constant rate. The root of this study is a microscopic financial model based on the multitype range-intensity contact process. The epidemic spreading of the MRIC model is considered as the spreading of the investors' investment attitudes towards the stock market, and we suppose that the investment attitudes are represented by the viruses of the MRIC model. These attitudes make the investors take buying stock positions, selling stock positions or neutral stock positions. Then, in order to compare the proposed financial model with the real stock markets, we adopt power-law distribution analysis and detrended fluctuation analysis (DFA) to investigate the stylized empirical facts. Furthermore, we make an approach at studying the nonlinear complex behaviors of returns for the proposed model and the real markets data by comparison, in an attempt to reveal the empirical laws in fluctuations of stock prices. Based on two kinds of graph based analysis of complex network theory, visibility graph (VG) [45,46] and horizontal visibility graph (HVG) [47], we proposed new random visibility graph and random horizontal visibility graph. We study the empirical relationships between the topological characteristic and the return time series with the random visibility graph algorithm. At last, by the Lempel-Ziv complexity (LZC) method (LZC can reflect the rate of new pattern generation of a series and evaluate the randomness of a finite sequences), we perform a series LZC analysis to study the complexity of the returns and the absolute returns. Also, we randomly sort the time series to compare with the original data, and the price data of Shanghai Stock Exchange (SSE) Composite Index and Shenzhen Stock Exchange (SZSE) Component Index are selected for the empirical research.

2. MRIC financial price model

The multitype range-intensity contact (MRIC) process on a configuration space is a continuous time Markov process which has different types of particles with different infection parameters. These infection parameters are the rates of Poisson processes which reveal the intensity of infection of the MRIC process. At the same time, the intensity of infection is connected with the range of the MRIC process, where the range represents the distance that a particle can travel in the process [41–44,48].

In this paper, the particles of the MRIC model stand for the attitudes toward investment of financial markets. The attitudes towards investment can be classified into three categories according to levels of strength: strong attitudes, weak attitudes, and neutral attitudes, corresponding to three types of particles, '2' type, '1' type and '0' type, respectively. This is also rational in the real world, since different investment attitudes in a real market are not always of same strength, some investors are more confident in their decisions while others are not so sure and relatively easy to transfer. The multitype range-intensity contact process on $\mathbb{Z}^d$ is a continuous time Markov process $\{\eta_s, s > 0\}$ with different infection parameters on the configuration space $\{0, 1, 2\}^{\mathbb{Z}^d}$, i.e., $\eta_s \in \{0, 1, 2\}$ for $x \in \mathbb{Z}^d$, $\eta_s(x) = 0$ is interpreted as vacant at site x and $\eta_s(x) = i$ $(i = 1, 2)$ is interpreted as that there is an 'i' type of particles at site x, and when $\eta_s(y) > \eta_s(x)$, then the birth is suppressed. We consider the initial distribution as v_{θ_1} and v_{θ_2}, that is, each site is independently occupied by type 1 particles with probability θ_1 and by type 2 particles with probability θ_2 $(\theta_1 + \theta_2 \leq 1)$, and let $\eta_s^{\theta_1,\theta_2}$ denote the state at time s of the MRIC model with initial distribution v_{θ_1} and v_{θ_2}. The most significant property of the MRIC process is that survival and extinction can both occur, which depend on the values of the rates $2^{-(L-1)}\lambda_1$ and $2^{-(L-1)}\lambda_2$, that denote the diffusion rates which reveal the intensity of infection in different range L $(L \geq 0)$ of strong attitudes and weak attitudes in this financial model. L is the range which represents the distance that a particle can travel.

We apply the MRIC price model for a certain stock price in financial market. Assume that the market for this stock consists of M (M is large enough) traders, who are located in a line $\{0, 1, \ldots, M\}$. At the beginning of each trading day $t (t = 1, 2, \ldots, T)$, we select two fractions of traders (with initial density θ_1 and θ_2) randomly in the dynamics who take weak attitudes and strong attitudes, respectively. Suppose that each trader can spread his attitude several times at each day, and let l be the time length of trading time in each trading day, we denote the stock price at time s in the tth trading