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The endogenous dynamics of financial markets: Interaction and information dissemination

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ABSTRACT

We investigate the process that different interactions between investors will prompt information to propagate along a differentiated path and construct a financial market model. As information spreads, increasingly investors are attracted to participate in trading, then the "herding effect" is magnified gradually, which will induce the topology of market network to change and the price to fluctuate. Especially, under different initial conditions or parameters, the peak and fat-tail property is produced and the obtained statistic values coincide with empirical results: the power-law exponents between the peak value of return probability distribution and the time scales range from 0.579 to 0.747, and the exponents between the accumulation distribution and the return on the tail are close to 3. Besides, the extent of volatility clustering in our produced price series is close to that of S&P 500 and locates between NASDAQ and HSI. All the results obtained here indicate that the continuous variation of the "herding effect" resulting from information propagation among interacting investors may be the origin of stylized facts of price fluctuations.

1. Introduction

In recent years, masses of financial data can be obtained more easily, many methods in statistical physics have been applied to the study on financial markets, and lots of stylized facts in financial markets have been accepted, such as peak-fat-tail non-normal behavior [1–7], long range correlation [8,9], volatility clustering [10,11] and so on [12–16]. Obviously, such stylized facts don't match the framework of rational exception and homogeny assumption. Then a new method is needed to give the corresponding explanation. Because an agent-based model could describe an agent's heterogeneity and bound ration more easily, lots of finance agent-models [17–28] have been built to search the underlying market mechanism. Almost all agent-based financial models are composed of two parts, one is trade rules, also called price determination in some literature, and the other is mechanism design. For the former, there are three types of rules to determine the price. The first [17–20] is that price evolves with the imbalance between supply and demand, as in Eq. (1)

$$p_t = f(p_{t-1}, D(t) - S(t)) \tag{1}$$

where $D(t)$ and $S(t)$ denote the demand and supply at time t respectively. The second [21–24,29] describes such a process: there is a true order book where agents post their offers to buy or sell shares, then the equilibrium price is decided to promote the trade volume to be maximized. The third [25,26] is that clearing price will be given by market makers at every step. For the latter, there are two types of mechanism design. The first focuses on the detailed description of agents' behaviors [19–22,29,25]. Generally agents learn from their past performances or from their neighbors, then inductively adapt their strategies. The second follows with interest in the heterogeneous interactions among agents and

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information dissemination [17,18,27,28,30–33]. To investigate information transmission and communication among agents, the percolation model is a good means [34]. It was introduced to the finance community by Cont and Bouchaud [17]. It can reproduce well the power-law distribution of the logarithmic returns and some other important stylized facts. After the initial CB model, many studies at "improvements" have tried to get more realistic results or make the model more reasonable [18,27,28,30–33]: the activity varies with feedback from the last price [30,35] or the size of cluster [27]; the connectivity parameter ranges from 0 to the critical value p_c [27] and so on. Motivated by the above ideas, we let the connectivity parameter p vary in a self-organized process and the activity be influenced not only by the last difference between demand and supply but also by the information arriving in the market. Especially, we further depict a detailed process of information transmission and communication among agents. As an open complex system, a financial market exchanges information with its external environment. Then the information, whose secret level and influence will vary over time, spreads along a differentiated path for different interactions between investors. A weighted scale-free network is used to describe heterogeneous interaction among people. As information spreads among people, increasingly investors are attracted to participate in trading and "herd behavior" is magnified gradually, which will induce the topology of the investors' trade network to change and the price to fluctuate. Compared with other models, our contribution is to describe a microscopic communication process between agents. Fortunately, our improved model will reproduce the non-normal scaling behavior of price fluctuation under different initial conditions and parameters. What's more, the statistic properties are also very close to the empirical results.

The text is organized as follows. Section 2 introduces the details of our model. Section 3 presents detailed analyses. Finally, Section 4 provides our conclusion and outlines some insights.

2. The model

In our model, there are two networks, one is the network of interaction relationship among people, and the other is the market network. The relationship network is described as a weighted scale-free network, containing $n(n = 10{,}000)$ vertices and nearly $5n$ edges. Here, a vertex V_i represents a person, weighed edge $e_{i,j}$ represents the relationship between persons V_i and V_j, and weight $w_{i,j}$ of edge $e_{i,j}$ represents the extent of intimacy of V_i and V_j. The weight $w_{i,j}$ obeys a uniform distribution between 0 and 1. The bigger the weight $w_{i,j}$ is, the closer persons V_i and V_j are, i.e. the stronger the interaction between persons V_i and V_j is. The market network is represented by a $L \times L(L = 100)$ von Neumann-type lattice, where each site has four neighbors. When a person participates in trading, he will occupy a site in the lattice. Then occupied sites which are interconnected will compose a cluster, also called an investor-group. All members in the same group will follow a common decision.

Note that a person is always in the relationship network, but only when he participates in trading will he exist in the market network. As shown in Fig. 1(a) and (b), only those solid occupied sites can represent investors who just join the market. In Fig. 1(c), the solid or blank vertices in the relationship network denote persons joining or not joining the market respectively.

Besides, information is denoted by a real number set $\{\mu, \eta\}$. The former μ obeys a uniform distribution between 0 and 1 and signifies its secret level; the latter η obeys a uniform distribution between $-\delta$ and δ and represents its influence on investors' decisions.

According to communication process theory and choice theory [36], we add the relationship network and consume the information composed by two properties $\{\mu, \eta\}$. In communication process theory, there are six components in the information spread process, such as communicators, audience, communication effect and so on. In choice theory, an audience can choose to receive the message or not. Taking these views into account, the information secret level and relationship between people are designed to reflect the choice process: information from the communicator can be received by the audience when they are intimate enough, namely when their intimacy degree is bigger than the information secret level. As for information influence, it's designed to quantitatively reflect the communication effect. For a variable, if it obeys a normal distribution, it will fluctuate closely to the center at a large probability, so such a distribution can't reflect the diversity. In order to assure the diversity, we use information secret level, information influence and the relationship between people which obey the uniform distribution instead of normal distribution. Despite this, we also have carried out some experiments when the above variables obey normal distribution, the corresponding analyses for these experiments are present in Table 7 and Fig. 16 in Section 3.

Initially, $M = 100$ investors randomly take up the sites of the lattice. Moreover a decision strategy ς, buying or selling or sleeping, is assigned to each group, which is denoted by 1 or -1 or 0 respectively.

2.1. Communication process between agents and dynamic evolution of investor groups

As an open complex system, a financial market always exchanges information with its external environment. Once a piece of new information arrives, all persons in the market will get it at once and some people will disseminate it. When information from the market spreads through the people's relationship network, some persons out of the market will join the market and be absorbed in investor-groups. Then investor-groups may grow up. Under the assumption that all members in the same group will follow a common decision and that the trade-volume of a group is equal to its size, continuous growth