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Evolutionary model on market ecology of investors and investments

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HIGHLIGHTS

- We present an evolutionary model on financial market ecology.
- The model investigates the dynamic behaviors of investors and investments.
- The model can self-organize to a quasi-stationary state.
- The system with investors and investments shows diverse dynamic behaviors.

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ABSTRACT

The interactions between investors and investments are of significant importance to understand the dynamics of financial markets. An evolutionary model is proposed to investigate the dynamic behaviors of investors and investments in a market ecology. The investors are divided into two groups, active ones and passive ones, distinguished by different selection capabilities based on the partial information, while the investments are simply categorized as good ones and bad ones. Without external influence, the system consisting of both investors and investments can self-organize to a quasi-stationary state according to their own strategies associating with the gains of market information. The model suggests that the partial information asymmetry of investors and various qualities of investments commonly give rise to a diverse dynamic behavior of the system by quantifying the fraction of active investors and of good investment at the quasi-stationary state.

1. Introduction

The financial market has been deemed as one of the most complex systems, in which the interactions of investors give rise to the dynamic evolution of asset price of investments. To understand the relationship between investors and investments in financial markets, a lot of models have been proposed by experts from the fields of economics and physics [1–12]. These pioneering works, such as the multi-agent-based Lux–Marchesi model [1], percolation-based Cont–Bouchaud model [2] and order-driven model [9,10], are shown to discover the underlying mechanisms of evolutionary financial market by reproducing the empirical properties found in them.

On the other hand, a group of experts pay more attention to the effect of market information on the investing activity of investors. The famous efficient market hypothesis (EMH) has stated that each investor in an efficient market has the same opportunity to earn average market gains, regardless of whether or not he takes any advice from experts or has any

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practices [13–15]. This fairness in EMH, however, is not quite convincing and is more or less contrary to the empirical observations. The reason has been found that there is some valuable market information that can be dug out to make return because they are not reflected instantly and completely from the market price [16–21].

On the basis of the above consideration, Zhang [22] proposed an alternative theory to reinforce EMH, in which he pointed out the existence of a small probabilistic margin in the market that can be exploited by smart (or active) investors, and that there is a quantitative relationship between the probabilistic margin and the amount of investment committed by the smart investors [23]. The following work carried out by Capocci and Zhang further showed that the active investors provided the driving force that make the passive investors obtain better gains [24]. These results suggested that the *partial information asymmetry* of investors generally exists in evolutional financial markets. Meanwhile, the market ecology of investors including active ones and passive ones was also investigated so as to understand the interaction among various investors in the given market uncertainties [25–29].

In this paper, we enlarge the research scope of market ecology under Zhang's framework, and study the dynamic behavior of not only investors, but also investments. In the toy model, all investment behaviors from both *active* and *passive* investors are made according to their own selection capabilities and strategies. And an investor is assumed to go bankrupt if his wealth decays to a very small value ($\approx$0), while an investment can survive only if its return is positive and vice versa. Without any external influence, the system of investors and investments can evolve in a self-organized manner to a quasi-stationary state, at which the fractions of active investors and of good investment are quantified to characterize the dynamic behaviors of the analyzed system. The results show that it leads to a diversity of dynamic evolvement by the partial information asymmetry and quality variation of investments in the financial market. We also should note that this toy model may be insufficient to reproduce the empirical properties found in financial markets because the updating strategy of investors and investments are simplified.

2. The model

The involved financial system consists of investors and investments. To mimic the intelligent inequality in the real financial market, two types of investors are taken into account, the active investors perceive more information inducing better selection capability D_c on good investment; while the passive investors perceive relatively less information inducing weaker selection capability D_s on good investments, where the subscripts, c and s, stand for active and passive. The partial information asymmetry of the financial market is behaved by the distinction of selection capability on good investments described as $D_c > D_s$. The perception of a passive investor is generally not worse than that of a noisy investor, namely $D_s \geq 0$ ($D_s = 0$ stands for the noisy investor). Hence both D_c and D_s belong to $[0, \infty)$. Analogously, each investments is set to be either good with quality Q_g or bad with quality Q_b, where the subscripts, g and b, stand for good and bad. It can be noticed that Q_g is higher than Q_b in the system, and we set $Q_g + Q_b = 1$ for simplicity.

It is assumed in the system to be invested there are M investments and N investors, each of whom has an initial wealth $W_i(0) = 1, i = 1, 2, \ldots, N$. Time is described by the integer variable t ($t = 0$ denotes the initialization of system). Assume p_c is the probability of introducing a new active investor when an investor goes bankrupt, so the number of initial active investors is Np_c, and the rest are deemed as passive investors. Analogously, there are Mp_g good investments in contrast to $M(1 - p_g)$ bad investments in the beginning, where p_g is the probability of introducing a new good investment when an investment goes dead.

Now we define two strategies for active and passive investors, respectively. For an active investor, the probability that he chooses a good investment is $P_g^c(t)$, which is defined as

$$P_g^c(t) = \frac{F_g(t) \times Q_g^{D_c}}{F_g(t) \times Q_g^{D_c} + (1 - F_g(t)) \times Q_b^{D_c}}, \tag{1}$$

with $F_g(t)$ the fraction of good investment at time t. So the probability that a bad investment is chosen by an active investor is $1 - P_g^c(t)$, correspondingly. Similarly, a passive investor will put his wealth on a good investment with probability $P_g^s(t)$ in contrast to a bad one with the probability $1 - P_g^s(t)$, where $P_g^s(t)$ is defined as

$$P_g^s(t) = \frac{F_g(t) \times Q_g^{D_s}}{F_g(t) \times Q_g^{D_s} + (1 - F_g(t)) \times Q_b^{D_s}}. \tag{2}$$

Because the partial information asymmetry leads to be $P_g^c(t) > P_g^s(t)$, we can deduce that the strategy of an active investor is superior to that of a passive investor.

Once an investor has chosen an investment, he will have a certain probability to win which is determined by this quality of the investment, a good one with probability of Q_g, as well as a bad investment of Q_b. If the ith investor wins, his wealth $W_i(t)$ will multiplied by a factor $m_w (m_w > 1)$, while the wealth of an investor who loses the game will be multiplied by a factor $m_l (m_l < 1)$. The positive (negative) logarithmic return of the investor is $\ln m_w$ ($\ln m_l$), and the absolute logarithmic returns should definitely be the same, namely $m_w \times m_l = 1$. At the same time, the investment gains the wealth from all the investors who choose it as its capital.

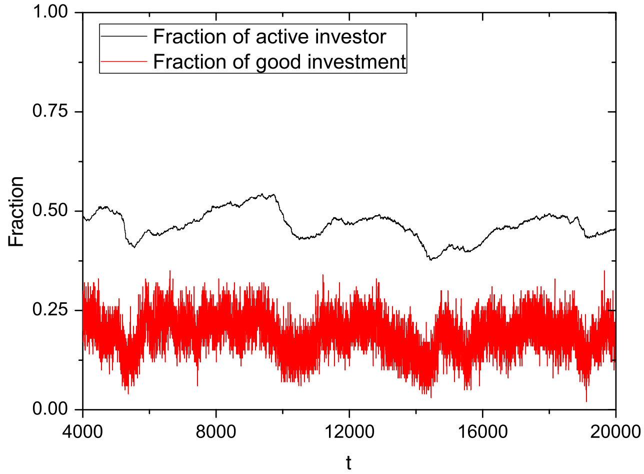

Fig. 1. (Color online) The fraction of active investors and fraction of good investments at the quasi-stationary state as a function of time t in the model with $N = 1000$, $M = 100$, $Q_g = 0.7$, $Q_b = 0.3$, $D_c = 2$, $D_s = 0.5$, $p_c = 0.1$, $p_g = 0.1$, $m_w = 1.09$. They fluctuate slightly around their quasi-stationary values F_c^* and F_g^*, respectively.

The status of the system would be updated when all the investors have made their choices. First, we scale the wealth of each investor to avoid an overflow of the system, via dividing it by the average wealth. An investor will go bankrupt if his wealth decays below a small value T ($T = 0.0001$), then be replaced by a new investor with initial wealth equal to 1, and is active with probability p_c or passive with probability $1 - p_c$, as well. Next, the returns of the investments are computed by subtracting the cost from its capital, which is the sum of the wealths from all his investors, and is scaled by multiplying $\frac{M}{N}$. The cost of the investment, on the another hand, is generally a function of Q, namely $S(Q)$, where Q is the quality of this investment and is restricted to $Q \in [0, 1]$ [30,31]. Here, we take $S(Q) = Q$ for simplicity. Thus, for a good investment j, its return is defined as

$$R_j = U_j \times \frac{M}{N} - Q_g, \tag{3}$$

where U_j is the capital and Q_g is the cost. The return of a bad investment shares the same definition, except to replace the cost with Q_b. The investment with negative return is regarded as relating to a corporation or a stock that is running bad, hence will be removed and then replaced by a new investment of good quality with probability p_g or bad with probability $1 - p_g$.

3. Simulation results

We now concentrate on the fractions of active investors, $F_c(t)$, and of good investments, $F_g(t)$, at time t, to characterize the dynamic behavior of the financial market, which can always fall into a quasi-stationary state after plenty of time steps, although there are several key parameters controlling the self-organized evolution of the model. At the quasi-stationary state, $F_c(t)$ and $F_g(t)$ do not strictly converge to constant values, but fluctuate slightly around their average values at whole time scale, respectively (see in Fig. 1), and we define these average values as the quasi-stationary values F_c^* and F_g^*. These quasi-stationary states of investor and investment affirm that the financial market analogously behaves as an ecological system [32].

To study how the parameters affect the evolution of the artificial financial market, we first present the quasi-stationary values of F_c^* and F_g^* versus ratio $\frac{N}{M}$ between the number of investments and investors, and we test $\frac{N}{M}$ under the condition with diverse values of N and M, such as the groups of (N, M) including $(1000, 200)$, $(750, 100)$, $(2000, 200)$, $(1500, 100)$ and $(2000, 100)$. As shown in Fig. 2, F_c^* and F_g^* are almost constant when $\frac{N}{M}$ changes from 5 to 20. This result implies that the system is insensitive to the number of investors and investments.

Next, the variation of the quasi-stationary values under the influence of the return of the investors is investigated and displayed in Fig. 3, from which we find that with increasing multiplying factor m_w, F_c^* shows an obvious decreasing trend. To understand this phenomenon, we firstly consider that the larger m_w makes a greater wealth fluctuation of single investor, which strengthens the bankruptcy risk of investors and the updating rate of a new investor. Secondly, as the introducing probability of an active investor is less than that of a passive investor, it leads to a decreasing trend of F_c^* as a function of m_w. On the other hand, F_g^* is nearly uniform no matter the increase of m_w, which suggests that m_w has a weak effect on the updating rate of investment although the whole wealth of system accumulates along with time. In addition, the convergency time of the system gets shorter as m_w increases (see the inset in Fig. 3), which implies that the balance of market ecology strongly associates with m_w.

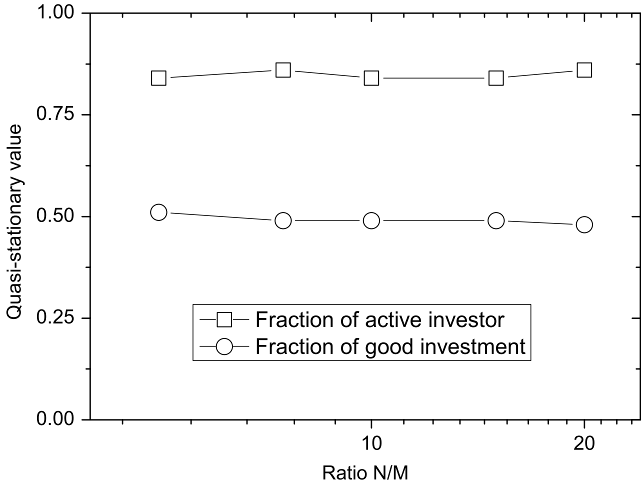

Fig. 2. The fraction of active investors and fraction of good investments at the quasi-stationary state as a function of ratio $\frac{N}{M}$ in the model with $Q_g = 0.7$, $Q_b = 0.3$, $D_c = 100$, $D_s = 0$, $p_c = 0.3$, $p_g = 0.3$, $m_w = 1.09$. Note that the horizontal axis is denoted by a logarithmic scale.

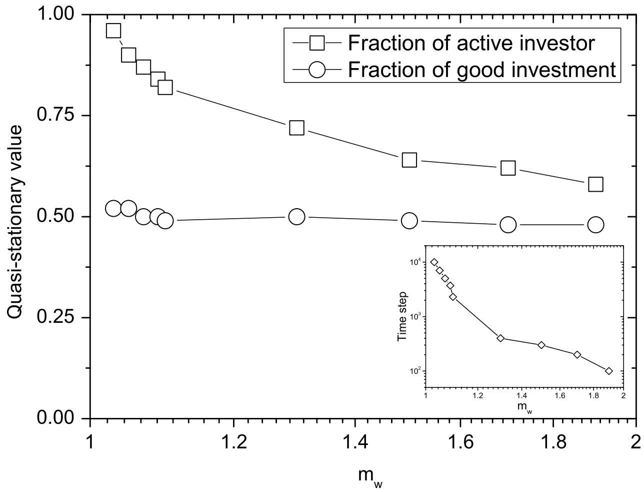

Fig. 3. The fraction of active investors and fraction of good investments at the quasi-stationary state as a function of multiplying factor m_w in the model with $N = 1000$, $M = 100$, $Q_g = 0.7$, $Q_b = 0.3$, $D_c = 100$, $D_s = 0$, $p_c = 0.3$, $p_g = 0.3$. The inset describes the convergent time of system reaching quasi-stationary state vs. m_w. Note that the horizontal axis is denoted by a logarithmic scale.

In Fig. 4, F_c^* and F_g^* are depicted respectively as functions of p_c and p_g, to quantify the effects of the introducing probabilities p_c and p_g on them. It is obvious that F_c^* increases with p_c, while F_g^* increases with p_g. However, F_c^* and p_g is weakly anticorrelated since F_c^* decreases with the increasing of p_g (see the left panel in Fig. 4). The reason is that small p_g is associated with a large fraction of bad investments in the financial market, thus it is more likely the passive investors put their wealth on the bad ones and go bankrupt while the active investors put their wealth on the good ones, leading to a high F_c^*. However, when p_g increases, the high fraction of good investments makes the passive investors resilient since they buy the good investments more often, which leads to a decreasing F_c^*. The right panel of Fig. 4 reveals that F_g^* positively correlates with p_c, as the active investors prefer to choose the good investments.

As mentioned above, the market information is actually unfair for each investor in a real financial market, and it is reflected in our model that every investor can only perceive partial information of the financial market due to his own selection capability, leading to diverse dynamic behaviors of the system. The investigation of the selection capabilities of active or passive investors effecting on the interaction between investors and investments is shown in Fig. 5. In Fig. 5(a), F_c^* and F_g^* vary with D_c when $D_s = 0$ is fixed, in the way that both F_c^* and F_g^* remarkably increase with the increasing of $|D_c - D_s|$. In addition, we present that F_c^* and F_g^* change with D_s when D_c is set large enough in Fig. 5(b), in which F_c^* and F_g^* behave differently. When D_s is raised, F_g^* stays nearly the same, whereas F_c^* becomes smaller, in that the selection abilities of the investors are getting homogeneous in the financial market. Therefore to some extent, the dynamic behaviors of investors directly relate with their heterogeneity in a whole financial market, while those of investments associates with the selection capability of active investors.

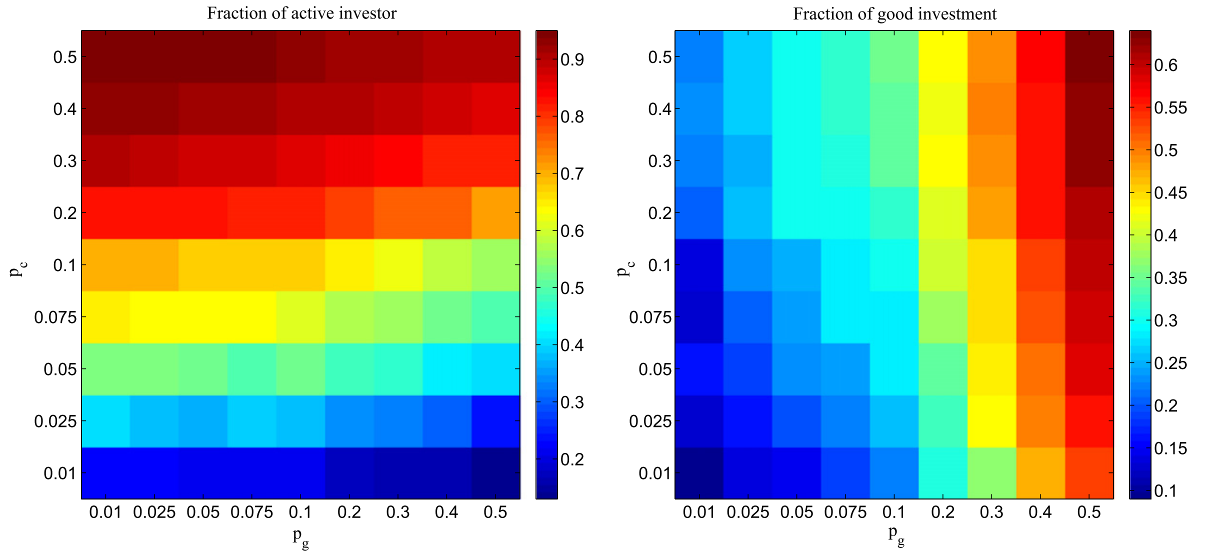

Fig. 4. (Color online) The fraction of active investors and fraction of good investments at the quasi-stationary state as functions of probabilities p_c and p_g in the model with $N = 1000$, $M = 100$, $Q_g = 0.7$, $Q_b = 0.3$, $D_c = 100$, $D_s = 0$, $m_w = 1.09$.

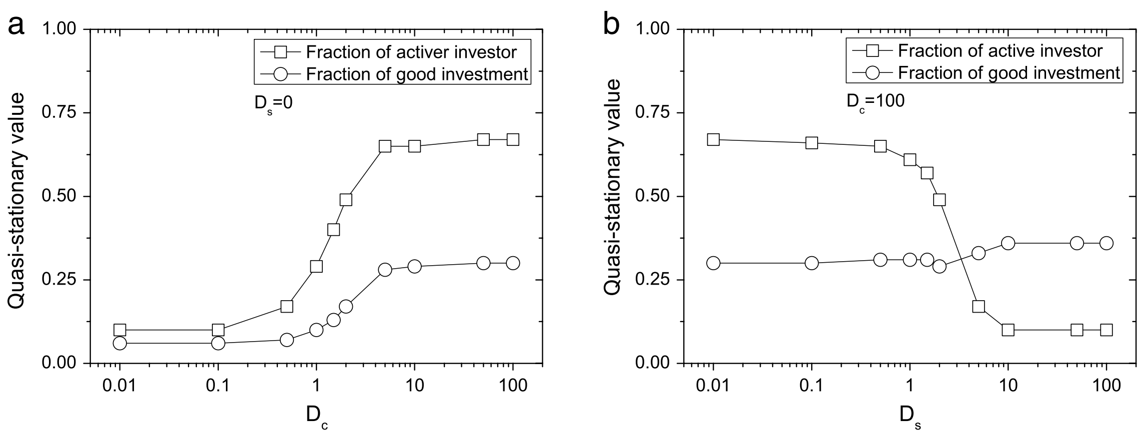

Fig. 5. The fraction of active investor and fraction of good investment at the quasi-stationary state as functions of selection capabilities D_c and D_s in the model with $N = 1000$, $M = 100$, $Q_g = 0.7$, $Q_b = 0.3$, $p_c = 0.1$, $p_g = 0.1$, $m_w = 1.09$. Note that the horizontal axis is denoted by a logarithmic scale.

To quantify how the quality of investments acts on the dynamic behavior of the system, F_c^* and F_g^* as functions of Q_g are investigated. The result is shown in Fig. 6. As Q_g increases, both F_c^* and F_g^* show a mono-increasing trend. This is prompted by a higher chance to choose good investments for the investors, especially the active ones, when Q_g is large, so that it is easier for them to win and earn more wealth. Although the cost increases with the quality of investment as well, its return is still positive for the capital received from the investors becomes much larger.

4. Conclusion

In conclusion, we describe the statistical properties of a simplified market model composed of investors and investments. The investors, according to their selection capabilities, are regarded as active or passive, resulting in the fact that in a financial market they can only perceive partial information to make the right decisions on investments. On the other hand, the investments can be only good or bad defined by their qualities. The good investments have a larger probability to attract investors to invest, with a higher cost yet. An interesting result is derived that without any external influence, the system can evolve in a self organized manner to a quasi-stationary state by the interaction between investors and investments according to their own strategies. This distinguished feature, coincidentally, is consistent with the work by Farmer [32] et al., who has illustrated that the dynamics of a stock market is comparable with that of an evolutionary ecology such as the population of biological species (i.e., the financial market can be referred to as the ecological system).

In order to further understand the evolving process, we analyze the dynamic behaviors of the fractions of both active investors and good investments at the quasi-stationary states by extensive numerical simulations. They suggest that the

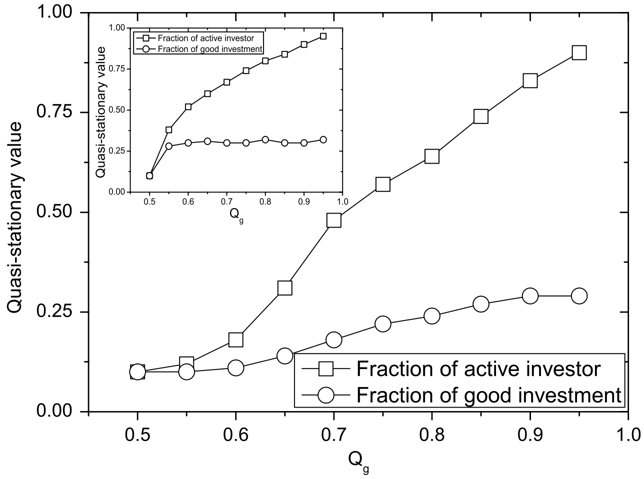

Fig. 6. The fraction of active investors and fraction of good investments at the quasi-stationary state as a function of quality Q_g in the model with $N = 1000$, $M = 100$, $D_c = 2$, $D_s = 0.5$, $p_c = 0.1$, $p_g = 0.1$, $m_w = 1.09$. The inset describes the system runs under extreme selection capability of investors with $D_c = 100$, $D_s = 0.5$, other parameters are the same as the main panel.

effects of the probabilities p_c and p_g on F_c^* and F_g^* exhibit different behaviors: F_c^* is positively correlated with p_c and weakly anticorrelated with p_g, while F_g^* increases with both p_c and p_g. Thus the partial information asymmetry of financial market and various quality of investments commonly result in the diversity of investors' and investments' dynamic behaviors. These results verify the emergence of diversity in financial markets as well as in population biology.

Actually, there are quite a few analogies between biology and finance. For instance, different values of parameters involved above lead to various quasi-stationary states with various fractions of investors and investments, which corresponds to the evolution process that different phenotypes evolve to a diversity of states with various population. Therefore, the perspective in the view of biology may provide vital clues to investigate the financial markets, since both the ecological systems and financial markets are complex systems with multi intelligent agents, and we hope that our work has given some insight, though not the answer, to the financial market ecology.

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