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Coupled effects of market impact and asymmetric sensitivity in financial markets

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ABSTRACT

By incorporating market impact and asymmetric sensitivity into the evolutionary minority game, we study the coevolutionary dynamics of stock prices and investment strategies in financial markets. Both the stock price movement and the investors' global behavior are found to be closely related to the phase region they fall into. Within the region where the market impact is small, investors' asymmetric response to gains and losses leads to the occurrence of herd behavior, when all the investors are prone to behave similarly in an extreme way and large price fluctuations occur. A linear relation between the standard deviation of stock price changes and the mean value of strategies is found. With full market impact, the investors tend to self-segregate into opposing groups and the introduction of asymmetric sensitivity leads to the disappearance of dominant strategies. Compared with the situations in the stock market with little market impact, the stock price fluctuations are suppressed and an efficient market occurs. Theoretical analyses indicate that the mechanism of phase transition from clustering to self-segregation in the present model is similar to that in the majority–minority game and the occurrence and disappearance of efficient markets are related to the competition between the trend-following and the trend-aversion forces. The clustering of the strategies in the present model results from the majority-wins effect and the wealth-driven mechanism makes the market become predictable.

1. Introduction

Since Alfred Marshall, exploring the functional form of market impact has been a laboring but valuable task for economists [1]. More recently, to elucidate the discrepancy between the stock price shaped by excess demand and the actual transaction price, econophysicists have also got involved in the research of the roles of market impact in the evolution of stock prices [2–4]. Their work has opened a new window for the study of complex behaviors in financial markets [5–11].

The market impact reflected in the increase and decrease of stock prices only tells us whether an excess demand exists or not, but not how it comes. Over the last decade, inspired by the findings in psychology that negative information should weigh more heavily on the brain than positive information, the roles of asymmetric sensitivity in the stock price performance have been studied by scientists [12–15]. It has been found that investors often exhibit asymmetric responses to positive (gain) and negative (loss) information [16,17]. They are prone to overreact to bad news and underreact to good news [18,19]. Such an effect may result in a change of the excess demand in the stock market.

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To have a deep understanding of the evolutionary dynamics in financial markets, some agent-based models have been introduced in modeling the strategic interactions between the investors [20–22]. Among them, the minority game (MG) provides us a simple yet effective way to model the evolution of stock prices [23–26]. In the MG, the evolutionary mechanism is determined by two main factors: global information and individual strategy. At each time step, each agent makes a buying or a selling decision depending upon the historical price information and his own trading strategy. After all the agents have made their decisions, the stock price is updated according to the excess demand. To get more benefits in the investment, an agent will learn from his past mistakes and choose the best-performing strategy from his strategy pool as his decision-making strategy [27–30]. Similar to the crowd–anticrowd problem in the MG, the herd behavior has also been studied in another repeated game, known as the Kolkata Paise Restaurant (KPR) problem [31–33]. Different from the two-choice competition in the MG, a macroscopic size of choices is considered in the KPR.

In the original MG, the individual strategy is a discontinuous variable. In exploring for the evolutionary mechanism of the strategies, it is somewhat difficult to give the descriptive nature of the strategies depending upon such a variable. As an extension of the original MG, the evolutionary minority game (EMG) introduced by Johnson et al. has incorporated continuous strategy sets into the MG. With such a continuous variable, the descriptive nature of the strategies is easy to be reflected, i.e. by the distribution or the standard deviation of the individual strategies [34–38]. In the EMG, the individual strategy is represented by a probability $g \in [0, 1]$. In decision making, an agent follows the outcome which can be predicted from the historical information with probability g and does the opposite with probability $1 - g$. An individual's strategy evolves according to its score. If the score of the strategy is below a threshold, it is modified within a certain range. The coevolutionary mechanism of the strategies and the stock prices in the EMG provides us more observable variables in the study of the market movement.

Although the roles of the market impact in the evolution of the stock prices have been widely discussed, both the coupled effect of the market impact and the asymmetric sensitivity and the coevolutionary mechanism of the individual strategies and the stock prices are still short of in-depth understanding. To address the coevolutionary mechanism of the individual strategies and the stock prices under different environmental conditions, in the present model, we incorporate the market impact and the asymmetric sensitivity into the EMG. The major findings of the present study are as follows.

(1) The change of the market impact parameter β can effectively affect the distribution of individual strategies. There exists a critical point β_c, below which the population tend to become clustering and above which the population tend to self-segregate into opposing groups.
(2) Both the individual strategy and the stock price are closely related to an individual's asymmetric response to gains and loses. With little market impact, the introduction of the asymmetry sensitivity leads to the occurrence of a single dominant strategy and a large price fluctuation. A linear relation between the standard deviation of the stock price changes and the average value of the strategies is found. With full market impact, asymmetry sensitivity only leads to the disappearance of the dominant strategies but not the stability of the stock prices.
(3) Theoretical analyses show that the occurrence of large price fluctuations is related to the majority-winning effect while the suppression of the large price fluctuations is related to the minority-winning effect. Under the conditions where market impact is small, the market movement is predictable and the agents in the majority win. Large price fluctuations are easy to occur in such a system. With full market impact, the market movement is unpredictable and the agents in the minority win. The stock price is somewhat stable and an efficient market is easy to occur in such a system.

This paper is organized as follows. In Section 2, the evolutionary minority game with market impact and asymmetric sensitivity is introduced. In Section 3, the simulation results of the coevolution of individual strategies and stock prices is presented and the roles of the market impact and the asymmetric sensitivity are discussed. In Section 4, the mechanisms for the movement of the dominant strategies is analyzed theoretically. The conclusions and an outlook of future studies are given in Section 5.

2. The model

We consider a model of N agents repeatedly trading in the stock market. Each agent has a trading strategy, also called gene value g. At each time step, each agent makes a decision of buying $(+1)$, selling (-1) or taking a holding position (0) according to the previous m outcomes of price movement and his trading strategy. For example, we use the symbols of $\uparrow$ and $\downarrow$ as the rise and the fall of the stock prices respectively. For $m = 3$, $(\uparrow\uparrow\uparrow) \downarrow$ represents the history in the memory, which means the price movement is down after three steps of rise. Faced with the global information $\uparrow\uparrow\uparrow$, the agent with strategy g will make his decision following the prediction $\downarrow$ with probability g and rejecting the prediction with probability $1 - g$. After all the agents have made their decisions, the stock price is updated according to the equation

$$P(t+1) = P(t) + sgn[A(t)]\sqrt{|A(t)|}, \tag{1}$$

in which $A(t) = \sum_{i=1}^{N} a_i(t)$, $a_i(t)$ is the decision of agent i [7,39]. At a given time, if there are more buyers than sellers, the stock price increases. If there are more sellers than buyers, the stock price decreases. The price information is stored in each agent's memory, which helps him make his prediction of the price movement in the next time steps.