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Overall fluctuations and fat tails in an artificial financial market: The two-sided impact of leveraged trading

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ABSTRACT

Recent years have seen leveraged trading playing an increasingly important role in financial markets. However, the effect of leverage on the markets is still an open question. Here, we introduce a framework to investigate leveraged trading through both agent-based simulations and controlled human experiments on a one-stock artificial market. It shows that leverage increases the market risks, and at the same time decreases the outbreak probabilities of financial bubbles or crises. This work helps to understand the impact of leverage on financial markets appropriately.

1. Introduction

In recent years, leverage has played an increasingly important role in financial markets all over the world [1–3]. Usually, leveraged trading means purchasing more of an asset by borrowing funds. And an important concept related to leverage is leverage ratio, which is defined as the ratio of an investor's total assets (his/her own wealth plus borrowed funds) to his/her own wealth. The use of leverage offers investors an opportunity to amplify their profits if the asset price changes in the way as they predict. However, greater risks come along at the same time. When the asset price moves against these investors, their loss will also be magnified. This two-sided nature of leverage has attracted enormous discussion around its influence on investors and firms [4–7], as well as on the whole financial markets [8–12].

Coricelli et al. [4] confirmed with a sample from Central and Eastern European countries that the total factor productivity growth of a firm increases with the rise of leverage ratio until leverage ratio reaches a critical level above which leverage lowers the productivity growth instead. Besides, Lang et al. in their paper [5] found that leverage ratio is negatively related to the growth of firms who either have poor growth opportunities or have good investment opportunities but not being recognized by capital markets. So we can see that although leverage can help firms to gain excess profits, the excessive use of leverage is to the obvious disadvantage of firm growth. But Jin and Zhou [6] pointed out one fact through a behavioral portfolio choice model that a sufficiently greedy behavioral agent is still willing to gamble on potential gains by using leverage despite the risk of catastrophic losses. From the aspect of financial markets, Thurner et al. [8] built a simple model of leveraged asset purchases with margin calls and found that leverage can cause fat tails and clustered volatility in the markets. And Feldman [9] showed that regulating leverage using margin calls can lead to less frequent financial crises, however, it creates harder hit of each crisis than without regulation. Furthermore, the excessive use of leverage is considered to be one of the main factors that created the latest global financial crisis [10,11]. By reviewing literatures on leverage, it can be seen that studying the effect of leverage is also of great practical application. It can either help investors and firms to make right investment decisions [4,7] or help economic policy makers to draft proper regulations [9,13,14].

In our paper, we design a one-stock artificial market in which the effect of leverage is tested. In our agent-based model on this market, there are two types of virtual agents, i.e., the intelligent agents and the quasi-random agents. The intelligent agents mainly represent institutional investors who can gain access to the use of leverage. When making trading decisions, these intelligent agents use heterogenous strategies which take the form modified from the famous minority game [15–19]. The quasi-random agents stand for small investors who cannot use leverage and only trade stocks in a

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small amount. When simulating the model, we only alter the value of leverage ratio of the intelligent agents, while the other market conditions and parameters including trading regulations are fixed. Through this controlled manner, we try to directly reveal the causation between the change of leverage ratio and the variations of statistical properties of the market. In addition, we also combine our agent-based simulations with controlled human experiments [20] to further show the reliability of our model design and to validate our simulated results.

Agent-based models [21–28] and controlled human experiments [20,29–33] have been regarded as two very promising new methods to explore economic systems. And the combination of these two methods to examine the same phenomenon is also shown to be a successful approach [34–42]. Thanks to these preceding researches by both economists and econophysicists mentioned above, we are able to raise the inspirations and ideas in combining the two methods to give a new point of view on the effect of leverage. This is where our work would stand out: to build a one-stock artificial market where leverage is available, combine the methods of agent-based simulations and controlled human experiments, and focus on the pure effect of leverage by fixing all the other parameters or conditions in the market. This work is of value for investors and firms as well as regulators of financial markets to understand and utilize leverage appropriately.

2. Methods

In this section, we adopt the essential ideas from both financial markets and leverage regulations to design a one-stock artificial market. In this market, both agent-based simulations and controlled human experiments are conducted.

2.1. The one-stock artificial market

In our artificial market, there is one stock that can be traded. And the market time is discrete which is denoted as t. Participants in the market can buy or sell the stock at any tick of the time. It is known that when trading in financial markets, investors should give their willing buy or sell prices and also the sizes of the orders for transactions, such like limited orders or market orders. However, for simplicity, participants in our market only need to decide whether they like to buy or sell the stock and their order sizes. Transaction price for all the orders at each time is generated through the market, which will be described later. After all the participants send their orders at a certain time t, the total demand (labeled as $O_d(t)$, which is the total amount of buy orders) and the total supply (labeled as $O_s(t)$, which is the total amount of sell orders) can be obtained in the market. It is a common sense that the stock price movement from $P(t)$ to $P(t+1)$ is determined by the excess demand at time t: the price will rise up if the total demand $O_d(t)$ is over the total supply $O_s(t)$, while the price will fall if the total supply $O_s(t)$ is larger. To quantitatively rule the price movements, we resort to [25,43] and get

$$\ln P(t+1) - \ln P(t) = \lambda\{\ln O_d(t) - \ln O_s(t)\}, \tag{1}$$

where λ is positive and called the market depth which represents the sensitivity of stock prices to excess demands. It can be seen from Eq. (1) that if λ is high, the market will fluctuate heavily when facing a large imbalance between the total demand and total supply; however, a deep market with a small λ can still be stable when in the same situation. Eq. (1) can also be written as

$$P(t+1) = P(t)\{O_d(t)/O_s(t)\}^{\lambda}. \tag{2}$$

Due to our discrete market time, we make another assumption that all the orders sent at time t are executed at the same transaction price which is the weighted average of $P(t)$ and $P(t+1)$:

$$P_{trans}(t) = (1-\beta)P(t) + \beta P(t+1), \tag{3}$$

where $\beta \in [0, 1]$. Now to sum up, the order transaction and price generating process is: all the buy orders $O_d(t)$ and sell orders $O_s(t)$ coming at time t will be executed at price $P_{trans}(t)$ defined in Eq. (3), and a new price $P(t+1)$ is generated from Eq. (2) when time flows discretely from t to $t+1$.

Next, we turn to the rules of leverage. In financial markets, the use of leverage involves many detailed and even complicated regulations that also usually vary from country to country. Here we only pick up the most general and essential rules of leverage to put into our artificial market: leverage qualification, leverage ratio, and margin call. Note that in this paper we mainly focus on the influence of different leverage ratios over statistical properties of the market, hence we control carefully over the other variables and conditions related to the participants and the market. And because the quasi-random agents (whose behaviors will be defined later) in the market get no access to leverage, the participants mentioned below refer only to the intelligent agents in our simulations or the human subjects in our controlled experiments.

- Leverage qualification: To begin trading in the market at $t = 0$, we give every participant the same initial portfolio: 10,000 cash, 1000 shares of the stock with an initial stock price $P(0)$ at 10, and zero debt. And by trading the stock along the time, wealth distributions of the participants will become diversified due to their heterogenous investment skills. Let $D(t)$ and $E(t)$ stand for the money and the equity (stock shares) a participant holds respectively at time t, then his/her total wealth $W(t)$ can be calculated by

$$W(t) = D(t) + E(t)P(t). \tag{4}$$

  So the total initial (own) wealth held by every participant is $W(0) = 20{,}000$. In our market, we rule that only the participants whose total wealth reaches a qualification level W_L can have the right to borrow funds from a lending institution and then trade with leverage. This is a reasonable simplification for leverage qualification because those participants with total wealth satisfying the required qualification level must be the ones who have better investment abilities. We set $W_L = 125\% W(0) = 25{,}000$, which means that an accumulated 25% return from the total initial (own) wealth is needed for a participant to meet leverage qualification.
- Leverage ratio (denoted as L_r): L_r is defined as the ratio of an investor's total assets (his/her own wealth plus borrowed money) to his/her own wealth. Note that L_r can be decided by another quantity called initial margin requirement (denoted as M_I). M_I is the least proportion of margin (which can be earnest money or equity) required when an investor opens a position with borrowed money. It can be seen that if an investor uses up the entire margin buying power, his/her leverage ratio is $L_r = 1/M_I$ accordingly. In our market, we regulate that a participant will use up all the margin buying power when his/her total wealth just reaches $W_L = 25{,}000$ at time t'. Therefore, with a margin of W_L, the participant borrows $B_r = (L_r - 1)W_L$ and his/her total wealth (his/her own wealth plus borrowed money) now becomes $W(t') = L_r W_L$. By setting this regulation, we guarantee that all the participants qualified for leveraged trading use the same leverage ratio so that we can study the pure impact on the market when a change occurs in the value of L_r.
- Margin call: In financial markets, another important quantity named maintenance margin requirement (denoted as M_M) is also regulated by lending institutions. M_M is usually lower than M_I in order to allow some fluctuations in stock prices. When an investor's margin falls below M_M after a great loss,