The Analysis of Stock Market Bubbles Using Agent-Based Models

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Project summary

The goal of this project is to analyze stock market bubbles using agent-based models. A stock market bubble is the situation when prices of stocks rise and become overvalued by any measure of stock valuation. Large fluctuations in the market might have a significant impact on the economy and population wealth. For example, the dot-com bubble crash decreased the market value of Nasdaq companies by $5.2 trillion over the period March 2000 through December 2002. Bubbles distort the behavior of investors; therefore, the assets in the economy might be inefficiently allocated. Moreover, the collapse of the bubble resulted in bankruptcies of numerous companies and poorer performance of institutional investors such as mutual funds and pension funds. Therefore, stock market bubbles as well as other bubbles in the economy such as a real estate bubble are always associated with negative consequences eventually despite the large initial returns.

In this context, the proposed research will enhance our knowledge about the formation of bubbles in the presence of partially irrational agents. The study will cover the period from 1995 through 2009. During the period, two stock market bubbles are documented: 1998-2001 (the dot-com bubble) and the recent 2008-2009 bubble. To my knowledge, this paper will be the first to compare these two stock market anomalies using agent-based models. The latter method is superior against the standard financial theory that is based on the efficient market hypothesis and rational representative agent paradigm. Micro-founded models usually are based on the assumptions that: *a*) agents

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are rational, *b*) agents are homogeneous, *c*) agents make decisions over an infinite planning horizon. However, all these assumptions do not align with the real world. Agent-based models give researchers an opportunity to incorporate above listed assumptions in the analysis. Therefore, the proposed study is likely to be more comprehensive and will provide with more accurate and very intuitive results.

The proposed research will be carried out over 12-month period. The main steps of the project include: *a*) a review of existing literature on irrational behavior of agents, *b*) a review of existing literature on equity market, trading, and stock exchanges, *c*) data collection and initial analysis of data, *d*) model development (model selection, model calibration or estimation, model validation), *e*) programming and simulation, *f*) analysis of results, *g*) summary of results, *h*) publication in a top journal.

The proposed research would provide an alternative explanation regarding the evolution of stock market bubbles, the factors that influence the appearance and magnitude of the bubble, and the ways the authorities could prevent the formation of stock market bubbles, as well as the methods to mitigate their sizes.

Contents

1 Introduction

Financial markets are the important institutions that should play a key role in effective assets allocation. In addition, financial markets serve as efficient price determination mechanism. The presence of the large number of profit maximizing traders, arbitrageurs, and institutional investors is believed to result in the fair value of securities traded. However, sometimes financial markets fail and stock market bubbles are observed. A stock market bubble is the situation when prices of stocks rise and become overvalued by any measure of stock valuation. Figure 1 shows the stock market performance over the period 1990 through 2009. Two stock market bubbles can be identified: 1998-2001 (the dot-com bubble) and the recent 2008-2009 bubble.

Large fluctuations in the market might have a significant impact on the economy and population wealth. For example, the dot-com bubble crash decreased the market value of Nasdaq companies by $5.2 trillion over the period March 2000 through December 2002. It accounts to approximately 27% decrease in Nasdaq capitalization. Bubbles distort the behavior of investors; therefore, the assets in the economy might be inefficiently allocated. Moreover, the collapse of the bubble resulted in bankruptcies of numerous companies and poorer performance of institutional investors such as mutual funds and pension funds. Therefore, stock market bubbles as well as other bubbles in the economy such as a real estate bubble are always associated with negative consequences eventually despite the large initial returns.

The goal of this project is to analyze stock market bubbles using agent-based models. The proposed research will enhance our knowledge about the formation of bubbles in the presence of partially irrational agents. The study will cover the period from 1995 through 2009. During the period, two stock market bubbles are documented: 1998-2001 (the dot-com bubble) and the recent 2008-2009 bubble. To my knowledge, this paper will be the first to compare these two stock market anomalies using agent-based models. The latter method is superior against the standard financial theory that is based on the efficient market hypothesis and rational representative agent paradigm. Micro-founded models usually are based on the assumptions that: *a*) agents are rational, *b*) agents are homogeneous, *c*) agents make decisions over an infinite planning horizon. However, all these assumptions do not align with the real world. Agent-based models give researchers an opportunity to incorporate above listed assumptions in the analysis. Therefore, the proposed study is likely to be more comprehensive and will provide with more accurate and very intuitive results.

The proposed research will be carried out over 12-month period. It will provide an alternative explanation regarding the evolution of stock market

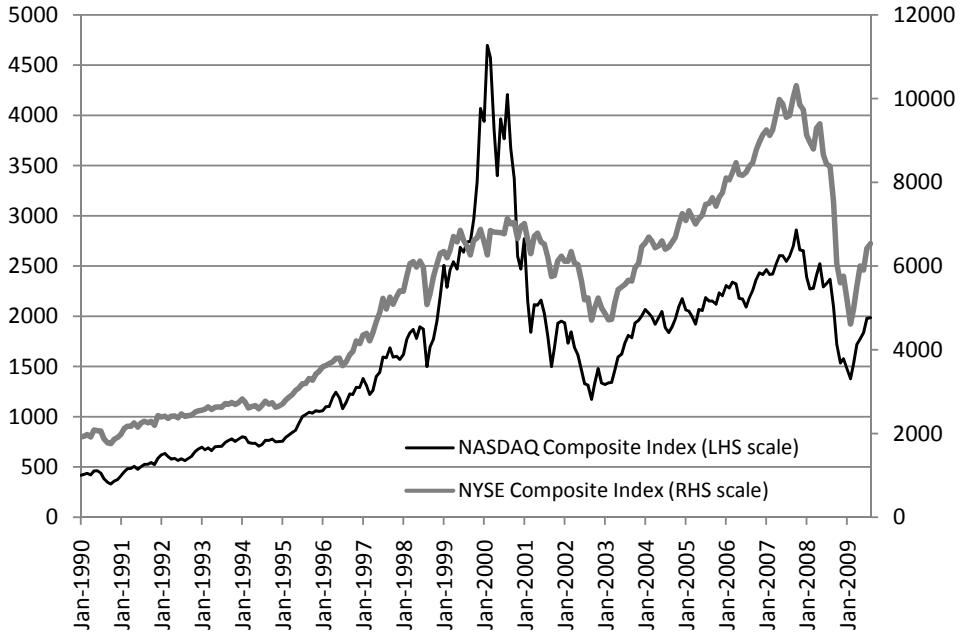

Figure 1: Stock market performance

bubbles, the factors that influence the appearance and magnitude of the bubble, and the ways the authorities could prevent the formation of stock market bubbles, as well as the methods to mitigate their sizes.

The rest of the research proposal is structured as follows. Section 2 discusses the related literature. The methodology is presented in Section 3. Section 4 describes the data sample. Section 5 describes briefly the research activities and time schedule. Expected results are detailed in Section 6.

2 Literature review

There is large array of literature focusing on stock market bubbles and agent-based models. It is impossible to acknowledge the vast literature on the subject, but several studies relevant to the topic of this paper should be discussed. Financial markets are quite well suited for agent-based models due to the several reasons (LeBaron, 2006). First of all, the assumptions regarding market efficiency and rational investors seem to be inconsistent with stock market and real estate bubbles. Second, we still do not fully understand certain features of financial time series. Agent-based models can provide a possibility for solving some of these puzzles. Third, financial

markets provide with a high quality statistic data, such as security prices and trading volume that can be easily analyzed. Such data also can be used for testing and calibrating agent-based models.

There were many attempts to use simulated stock markets and agent-based models of stock markets in order to mimic the stock price evolution and behavior of traders. LeBaron et al. (1999) show that the artificial stock market is able to replicate certain time series features from real markets, namely, predictability, volatility, and volume relations. LeBaron (2001) finds that populations with both short-horizon and long-horizon agents increase return variability, and leave patterns in volatility as well as trading volume similar to actual data.

Hommes (2006) discusses the properties of simple dynamic heterogeneous agent models. These models are highly nonlinear. However, the aggregation of decisions of agents (at the micro level) may generate sophisticated structure at the macro level. Hommes (2006) states that simple dynamic heterogeneous agent models can generate important stylized facts such as persistence in asset prices, unpredictability of returns at daily horizon, temporary bubbles and trend following, sudden crashes and mean reversion, excess volatility, clustered volatility and fat tails in asset returns. Importantly, in financial market applications, such models are able to replicate stylized facts. In addition, heterogeneous agent models generate high and persistent trading volume in sharp contrast to no trade theorems in rational expectations models.

Ofek and Richardson (2003) analyze the rise, persistence, and eventual fall of Internet stock prices. The authors link the Internet bubble burst to the unprecedented level of lockup expirations and insider selling. Henker and Owen (2008) adapt an experimental financial market model to field market data. The authors find that the experimental model is a reliable predictor of field market bubble bursts in more than 77% of the cases.

In this context, we believe that agent-based models are the most suitable method to analyze stock market bubbles and related issues. Further, we discuss methodology we intend to use in the proposed project.

3 Methodology

In the analysis, the following research design will be used. We develop an agent-based model of stock market. We assume that in the artificial stock market there are one stock and two kinds of agents: rational agents and irrational agents. In each period, each agent is either a potential buyer or a potential seller on a random basis. They can buy/sell only a single share

each trading period. The buyers submit bid orders to the stock exchange. Similarly, the sellers submit ask orders. The stock exchange collects the orders and generates the market price that ensures the maximum trading volume. Therefore, if submitted bid is equal or higher than the market price, the transaction is executed. Similarly, if submitted ask is equal or lower than the generated market price, the trade occurs at the market price.

We assume that rational agents approximately know the *fair* share price, P. In each period t, a rational agent generates her reservation price of the share, P_t^r that is normally distributed:

$$P_t^r \sim \mathbb{N}(P, \sigma^r), \tag{1}$$

where σ^r is relatively small number that is introduced to generate heterogeneity among rational agents. Irrational agents do not know the *fair* share price of the stock. Irrational agents can be either overoptimistic or overpessimistic. The proportion of irrational agents that are overoptimistic/overpessimistic can be proxied by investor confidence index. The reservation share price for overoptimistic/overpessimistic irrational agents, P_t^i depends on share price in the previous period, P_{t-1}, expected share price increase/decrease, ω, and standard deviation, σ^{irr}:

$$P_t^{irr} \sim \mathbb{N}(P_{t-1} \pm \omega, \sigma^{irr}). \tag{2}$$

The definition of rational and irrational agents implies that $\sigma^r < \sigma^{irr}$. Such a structure of the model will ensure that stock price will grow with investor confidence index and vice versa. If investors are overoptimistic during relative long time period, then stock price increase will lead to stock market burble. However, sudden drop in investor confidence index is likely to result in bubble burst. Expected share price increase/decrease, ω, can be calibrated using historical date and previous studies.

The intuition of the model can be illustrated by the following examples. Let's consider four cases. According to the **first scenario**, stock price is above its fair value and the number of overoptimistic irrational agents exceeds the number of overpessimistic irrational agents. In this situation, we expect that:

- majority of rational investors who are set on random basis to be sellers sell their shares,
- majority of rational investors who are set to be buyers do not buy any share,
- irrational investors are intensively trading (mostly buying) as they believe that stock price will keep rising,

- the number of potential buyers exceeds the number of potential sellers; therefore, share price is further growing.[1]

In the **second case**, stock price is above its fair value but the number of overoptimistic irrational agents is lower than the number of overpessimistic irrational agents. In this situation, we expect that:

- majority of rational investors who are sellers sell their shares,
- majority of rational investors who are set to be buyers do not buy any share,
- majority of irrational investors are trying to sell their shares,
- the number of potential sellers exceeds the number of potential buyers; therefore, share price is falling. Bubble burst is observed.

In the **third case**, stock price is below its fair value and the number of overoptimistic irrational agents is lower than the number of overpessimistic irrational agents. In this situation, we expect that:

- majority of rational investors who are buyers buy shares,
- majority of rational investors who are set to be sellers do not sell any share,
- majority of irrational investors are trying to sell their shares,
- the number of potential sellers exceeds the number of potential buyers; therefore, share price is further decreasing.

In the **last scenario**, stock price is below its fair value and the number of overoptimistic irrational agents is greater than the number of overpessimistic irrational agents. In this situation, we expect that:

- majority of rational investors who are buyers buy shares,
- majority of rational investors who are set to be sellers do not sell any share,
- majority of irrational investors are buying shares as they believe that stock price will keep rising„

[1]Majority of rational investors (not ALL rational investors) who are set on random basis to be sellers (buyers) sell (buy) shares because due to heterogeneity among rational agents it is possible that for some rational agents it is optimal to behave differently. The same idea holds for other cases as well.

- the number of potential buyers is greater the number of potential sellers; therefore, share price increases until it reaches fair value.

As we see the share price evolution is driven by supply and demand forces. In presence of excess supply, share price is likely to decrease. Similarly, if the demand is higher than supply, share price is expected to increase. In addition, we might assume that rational agents are able to forecast one period in the future (with some forecasting error). Then, it would be optimal for rational agents to buy shares when they are overpriced hoping to sell the shares in the next period. This would introduce the speculative behavior in the model.

To analyze the factors that influence the appearance and magnitude of the bubble, and the ways the authorities could prevent the formation of stock market bubbles, as well as the methods to mitigate their sizes, we will introduce capital gain tax in the model as well as trading restrictions. In addition, the analysis of stock market stabilization will be conducted by introducing the market maker who buys/sells large amounts of shares.

4 Data

In this project, we will use U.S. stock exchange data, namely returns on NYSE and Nasdaq indices. The study will cover the period from 1995 through 2009. During the period, two stock market bubbles are documented: 1998-2001 (the dot-com bubble) and the recent 2008-2009 bubble. Investor confidence index that determines the the proportion of irrational agents that are overoptimistic/overpessimistic is expected to be very important in the analysis. For robustness, we will use several indices and their lagged values to avoid endogeneity.[2]

5 Research activities and time schedule

The proposed research can be separated into several research activities:

1. a review of existing literature on irrational behavior of agents,

2. a review of existing literature on equity market, trading, and stock exchanges,

[2]It is likely that stock market performance and investor confidence index are interrelated. For example, because share price is growing, investors believe that the trend will continue in the near future. Therefore, they keep buying shares. This eventually leads to the further increase in share price.

Table 1: The research activities and time schedule

#	Activity	Time period
1	Literature review on irrational behavior of agents	Jan. 1 – Jan. 15
2	Literature review on on equity market and stock exchanges	Jan. 16 – Feb. 1
3	Data collection and initial analysis of data	Feb. 2 – Feb. 15
4	Model development	Feb. 16 – May 1
5	Programming and simulation	May 2 – July 1
6	Analysis of results	July 2 – Sep. 1
7	Summary of results	Sep. 2 – Oct. 15
8	Publication in a top journal	Oct. 16 – Dec. 31

3. data collection and initial analysis of data,
4. model development (model selection, model calibration or estimation, model validation),
5. programming and simulation,
6. analysis of results,
7. summary of results,
8. publication in a top journal.

We think that the project will be carried out over 12-month period. The research activities and time schedule are summarized in Table 1. We acknowledge that the schedule is very preliminary and it might be changed over research period. However, we think that the proposed research activities and time schedule truly reflect the complexity of the exercise and our proposed goals.

6 Expected results

We expect that our proposed methodology will be suitable to model the evolution of the bubble and its burst. We believe that the the proposed research would provide an alternative explanation regarding the evolution of stock market bubbles. The analysis will identify the factors that influence the appearance and magnitude of the bubble. The project is expected to have social contribution by providing the ways the authorities could prevent

the formation of stock market bubbles, as well as the methods to mitigate their sizes.

Furthermore, to my knowledge, this project will be the first to compare two stock market anomalies (1998-2001 (the dot-com bubble) and the recent 2008-2009 bubble) using agent-based models. The thorough analysis will help answer the question what the similarities and differences of the two bubbles are as well as how well we have learned the lesson related to the dot-com bubble burst.

The analysis will contribute to the existing literature by providing the impact of investor confidence on the bubble formation and its burst. The findings will show the importance of the expectations of investors. We expect that the obtained results will propose to increase regulation in the stock market in order to reduce the magnitude of irrational expectations of investors as well as the impact or irrational expectation on stock prices.

At last, the results of the proposed research will be summarized for publication in a top journal.

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