An Introduction to Agent Based Modelling

Reetish Padhi
(reetish.padhi@students.iiserpune.ac.in)

August 2021

Abstract

The purpose of this report to introduce the concepts involved in Agent Based Models (ABM) and to highlight their need in financial modelling. There is a discussion of the advantages and disadvantages of ABMs compared to traditional Stochastic and Representative Agent Models. Subsequently ABM concepts are used to simulate a toy model of a Stock exchange. This model although not completely accurate does help demonstrate the methodology used in Agent based modelling and offers some insight into the movement of stock prices.

---

1 Introduction

The global financial system is arguably the most complex system developed by humanity. The financial market consists of multiple 'agents', each agent contributing to net demand and supply which ultimately drives the price higher or lower respectively. However, the dynamics that arise due to fluctuations in demand and supply can be very difficult to understand and predict. There are many mathematical approaches to modelling financial markets. Stochastic models model stock price as a realisation of a Brownian motion. Stochastic modeling uses random variables to forecast the probability of various outcomes under different conditions. Unlike deterministic models these models give random results and hence have an element of uncertainty ingrained in them. This is important because market movement can be impossible to predict at times and stochastic tools are used to predict portfolio returns based on the stock return probabilities.By making assumptions about the random component of a model, stochastic models allow the validity of the assumptions to be tested statistically, and produce estimates not only of the expected value of the future payments, but also of the variation about that expected value. The other most popular approach of financial modelling is Representative Agent Modeling.These are models which consider the overall effect of market participants to be well represented by a single 'Representative Agent'. So instead of considering multiple agents and their interactions we assume that the representative is a good 'average' measure of all market participants. This simplification makes it slightly easier to study the overall effect of a large number of agents by just knowing their 'average' behaviour. However these approaches have certain limitations and that is where we have the need for Agent Based Models.

2 Limitations of Traditional Approaches

Traditional models make a couple of very strong assumptions about the markets and may be tad too idealistic to model some aspects of the markets. These assumptions are:

- Efficient Market Hypothesis
- Rationality of agents
- Homogeneity of the agents

2.1 Efficient Market Hypothesis

The Efficient Market Hypothesis (EMH) states that all relevant information is reflected in the current stock price and hence the stock always trades at it's "Fair" price. EMH implies that it is not possible to profit undervalued stocks or sell stocks at inflated prices because at every moment of time the stock is trading at it's fair price so any gains/losses are pure luck. From experience, we know that during bubbles and market crashes stocks tend to be trading at extreme inflated and discounted prices respectively so such assumptions may not be able to give reliable predictions in such cases.

2.2 Rationality of Agents

A rational agent refers to market participants and how they arrive at decisions in the market. Every agent tries to optimise their profits based on their knowledge and strategies which may have been developed from prior experience. That main issue with this assumption is that in some cases complete information is not available to the agents and more often than not, agents have to make decisions without complete knowledge.

2.3 Homogeneity of agents

Most of the representative agent models consider agents to be homogeneous(behave similarly) however this is a rather far fetched assumption to make. The market consists of thousands of traders and investors each of which have different strategies and opinions about the market. Moreover not all information is distributed evenly among participants.This is biggest advantage of using Agent Based modelling because we are able to model any number of agent types and strategies.

Stochastic models assume that stock returns follow a log normal distribution and thus, aren't able to explain stylised facts like volatility clustering and fat tails of stock returns distribution. Representative agent models do a good job at predicting the empirical moments but don't fit the data very well. Moreover events like market crashes are rare but have huge impact on portfolio returns. ABMs make the study of such rare events easier.

3 Agent Based Modeling

Agent based Modeling a way of modeling a complex system using individual entities called agents, each possessing its own set of actions(strategies) and relations with other agents in the system. ABMs typically have the following components:

3.1 Agents

These are the entities that interact with each other to give birth to the dynamics of the system as a whole. Each agent also possess a set of Rules for Decision making(Strategy used by agents) and Adaptive Learning.

3.2 Topology

The topology is essentially the mechanism through which agents can interact with each other. The topological structure can be thought of as a network that allows agents to communicate with each other and the rules determine the communication forms that the agents can have with one another in the given topology.

3.3 Environment

Environmental factors can be thought of as external shocks/perturbations that can affect the dynamics of the system. In the case of stock market, it can include things like news, commodity prices, government policies etc.

4 Advantages of ABMs

ABMs allow us to model several participants, each with different strategies and rules. This allows us to model rather complex systems without making strong assumptions like those mentioned in a previous section. This means we can incorporate irrationality, agent disagreement(which can cause larger volatility), agents with different mentalities (chartists/

fundamentalists/ noise traders) and even information heterogeneity where some agents have access to more information than others thus giving them an advantage. We allow the micro interactions to predict and give rise to macro interactions. This gives rise to emergent phenomena where we merely define the behaviour of the agents instead of assuming that the actions of many agents give rise to a particular outcome. This allows us to model non linear behaviour quite easily.

5 Agent Based Model of the Stock Market

5.1 Agent Types

• Chartists: These are the so called swing/momentum traders who tend to buy appreciating stocks (stocks with high momentum) and usually book profits once the rally has finished. Thus these agents are more concerned about ΔP.

• Fundamentalists: The fundamentalists tend to buy a stock when they feel it has fallen well below it's 'fair' price and sell the stock once they perceive it as expensive.

• Noise Traders: These are the intraday traders and they are responsible for creating the noise in the prices.They have been modelled as buying/selling randomly.

5.2 Strategies Employed

At the beginning of each iteration the participant decides to either buy or sell with equal probability. Once the decision of buying has been made, the trader evaluates the call utility function and buys 10 quantities of the stock with the largest call utility. If they decide to sell, they evaluate the put utility function for all stocks in their portfolio and sell all of them at once. If the trader isn't holding any stocks when selling then no action is taken. Buying or selling stocks consumes the liquidity in the market and raises or lowers the price accordingly. These functions are discussed in detail in the following section.

5.3 Environment

The stock market is composed of 5 stocks. The traders buy stocks in multiples of 10 and as a result absorb the liquidity and lead to rise or fall the price of the stock by a fixed amount. The agents decide to buy or sell in one time-step with P(buy) = P(sell) = 0.5. When Buying, the agent prefers to buy 10 quantity of the stock with the highest call utility value and when they decide to sell a stock, they sell all their shares of that particular stock from their portfolio. Short positions are not allowed (equity market). The order in which traders buy/sell stocks is randomly decided.

5.4 Call-Put Functions

$U_s = \alpha/P_s + \Delta P_s$
$V_s = P_s$ - $\beta \Delta P_s$

where,
P_s - Price of the stock
ΔP_s - Change In the price of the stock in the previous timestep (Momentum of the stock)
α , β - Positive Constants
U_s - Call Utility
V_s - Put Utility

The advantage of using such function is that we can model both fundamentalists and momentum traders. The ΔP term implies that larger movement would increase the utility function and thus make it more likely for a trader to buy the stock. Similarly the 1/P term implies that investors would prefer to buy a stock available at a cheaper valuation. The noise traders buy and sell a particular stock randomly. The α term can be thought of as the measure of the proportion of fundamental to momentum traders. If alpha is very high the contribution of the 1/P is much larger than the ΔP term and hence fundamental trading style would be dominant. Similarly if α is very low, the ΔP term is much larger meaning the momentum trading style is dominant. Note that one participant can trade according to the fundamental term (1/P) or the ΔP term, thus there is flexibility in the trading strategies one can use. The β term in the put utility function is similar to the α in the call utility.

6 Simulations

6.1 Highly Liquid Markets

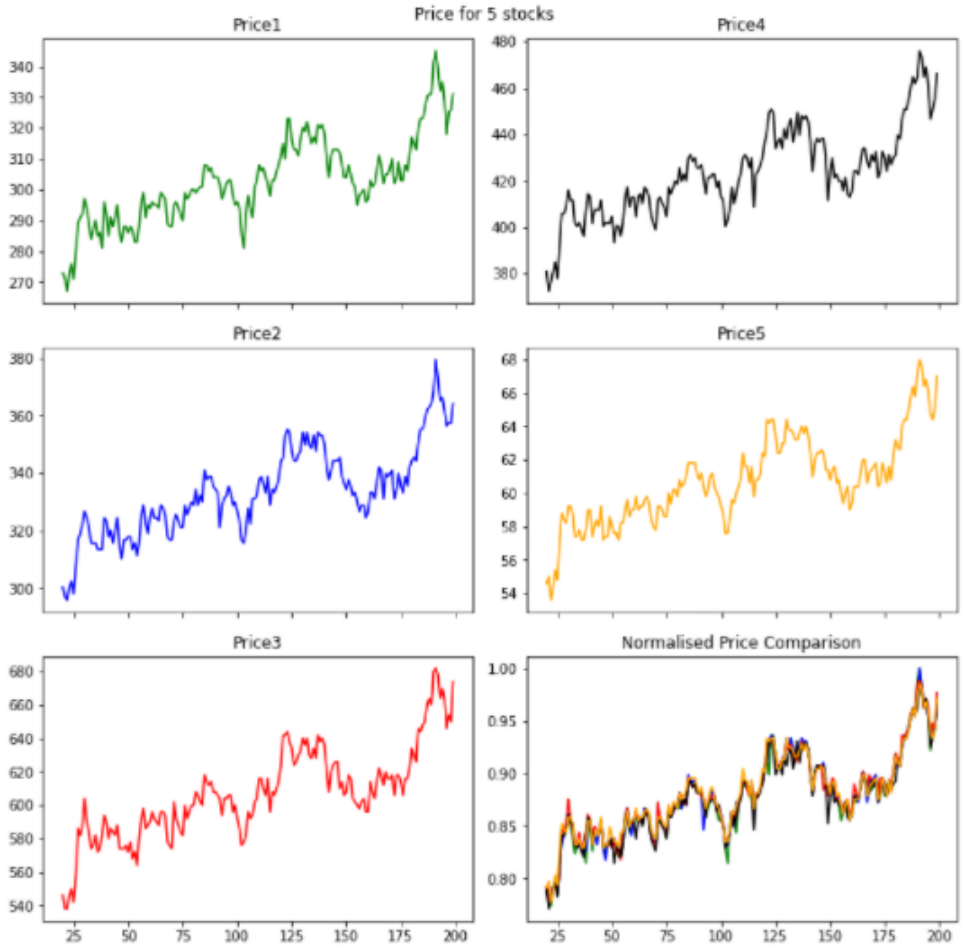

Figure 1: Market Participants 40

Here we have initialised the 5 stocks with random prices and we see how they evolve according to the agents' actions. In the last plot we compare the evolution of the 5 stocks by taking the normalised values of the prices. We notice that the stock movements are correlated. Usually it is observed that stocks belonging to the same sector tend move together. This basic model is able to capture such correlation well. However it is not always necessary that all stocks of a sector perform equally. This model is unable to account for such unequal performance. One way to model that could be to alter the values of α and β for each stock instead of having one common value for all of them. α and β are the terms that essentially control

the ratio of the fundamental and momentum traders. In this simulation we assume more or less similar fundamentals but one can change this by taking different values for the stocks. The logic being that stocks with better fundamentals would attract more fundamentalist type strategies and that might introduce a more realistic variation/correlation between the stocks.

6.2 Low Liquid Markets with Less Market Participants

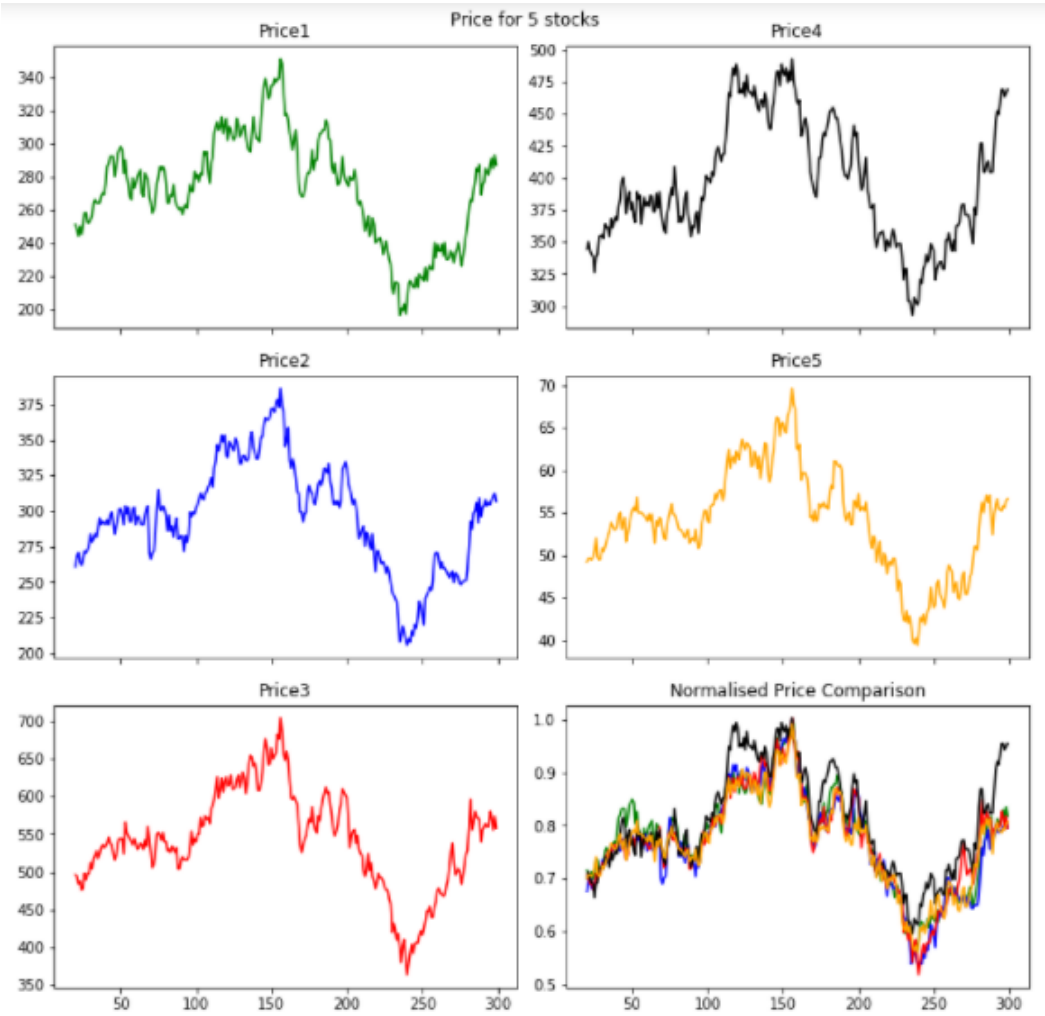

Figure 2: Market Participants 20

Here we have reduced the number of participants in the market by half. With lesser participants we can see larger differences in the performance of the stocks. However the stocks are

still correlated as is evident in the final plot. In a way lower liquidity is creating a difference in the returns of stocks with similar 'fundamentals'.

6.3 Low Liquid Markets with Larger Bid-Ask Spread

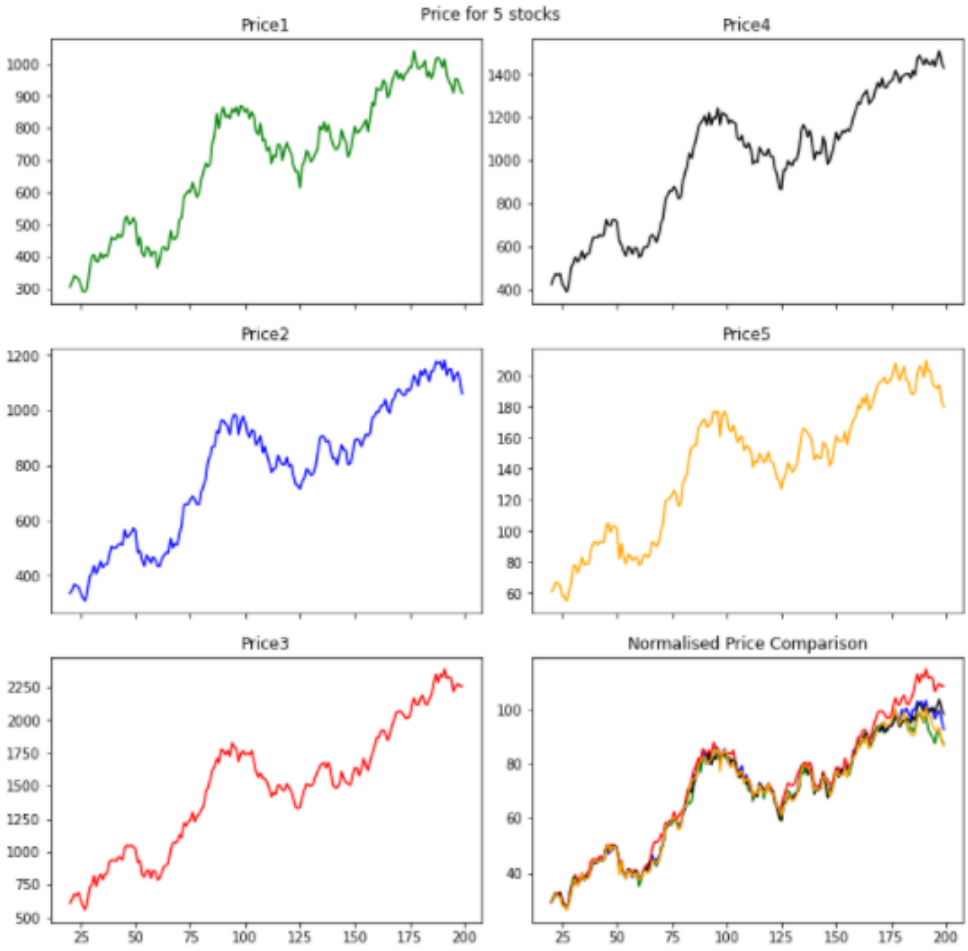

Figure 3: Higher Bid ask Spread

Here instead of having lower market participants we increase the bid ask spread. The bid-ask spread is essentially the difference between the highest price that a buyer is willing to pay for an asset and the lowest price that a seller is willing to accept. Thus a larger bid-ask spread essentially implies that there is uncertainty/confusion in the minds of both buyers and sellers. This can lead to higher volatility and we can observe that in the last plot towards the end.

6.4 Effect of Noise Traders

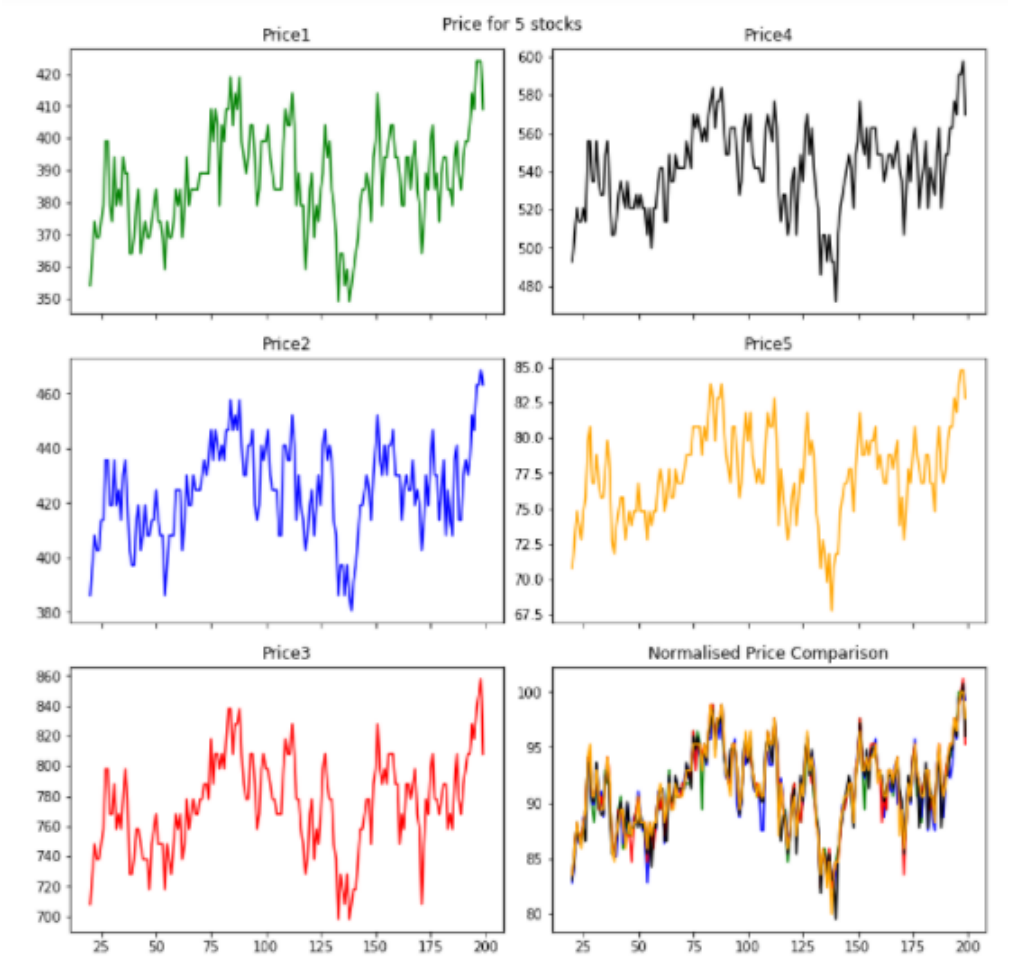

Figure 4: Without Noise Traders

Notice that in the absence of the noise traders the volatility of the stocks falls drastically and we don't observe any bull/bear runs unlike in the previous plots. In a way it is the noise traders that give rise to the perturbations which creates opportunities for the other traders in this model.Thus noise traders also form an integral part of the stock market in this model.

7 Conclusion

Although ABMs offer high flexibility and solve a lot of issues with other models, they have some disadvantages as well. It is rather difficult to make quantitative predictions using

ABMs and most of the time we must be satisfied with qualitative properties. It is not very easy to generalise and construct theorems using ABMs. ABMs can also be computationally expensive. Each agent is demanding calculations from the CPU. When this number gets too large it can lead to a computer seriously slowing down. Moreover the use of free parameters is another feature of ABMs which can be thought of as a con because such parameters are decided manually by the researcher.

8 References

• Agent-based models in financial market studies - L Wang, K Ahn, C Kim and C Ha
• Understanding agent-based models of financial markets: A bottom-up approach based on order parameters and phase diagrams - R. Lye, James Tan, S. Cheong
• The Genoa Artificial Stock Market: Microstructure and Simulations - M. Marchesi, S. Cincotti, S. Focardi, M. Raberto
• https://simudyne.com/wp-content/uploads/2019/08/A4-Guide-to-ABM-FINAL-5.pdf
• Documentation for mesas Library