From multi-agent modeling to microscopic market dynamics: A statistical physics approach

PhD theses

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1 Motivation

Recently statistical mechanics methods have been used to study several types of complex systems outside the traditional scope of physics. The idea to apply techniques developed in scaling, disordered systems, non-equilibrium and critical phenomena, to social and economic systems is based on the fact that all these fields deal with ensembles of a large number of interacting agents. Large part of the studies have been statistical analysis of financial data, often looking for universal "stylized facts" in finance. However, in case of financial systems, as opposed to physical ones, we are far from having an understanding of the governing dynamics.

A subfield of econophysics that has not gained large attention up to now is the study of traders' behaviour through analysis of microscopic market dynamics. Apart from the fact that this study is intellectually appealing bringing together many disciplines (economics, psychology, data analysis, physics, mathematics, sociology), it may also result in a rapprochement between econophysicists and economists. There are two contradicting paradigms in today's economics, making the scientific approach similar to a question of faith. Traditional economists believe that financial actors are rational and that markets can be modeled through a representative agent. This paradigm is partly based on the desire to develop economics to be a hard science with theorems and proofs, similar to mathematics. This school of thought achieved important intellectual results and helped to clarify several notions, furthermore effaced verbal and ideologically based economics. However, because of the strong simplifying assumptions, the results were often far from real world experience. On the other hand many economists in the past decades argued that the market often exhibits situations when the traders do not behave in a rational way (and simply their goals are not identical) and that in order to create a microscopical description of markets we need to apply paradigms from soft disciplines such as psychology.

In my work I try to identify and separate market processes where traders' behaviour plays a major role, from the cases when empirical results can be reproduced without assumptions on the agents' comportment and attitude.

2 Goals

With the research I would like to gain a better understanding of the dynamics that govern stock markets. Particularly I am interested in drawing a connection between the microscopic dynamics of trading in stock markets and the strategic behaviour of the traders. My approach to this problem is to analyse market data, and try to reproduce the empirical results with simple models, applying the least number of behavioural assumptions. These models enable us to discriminate between phenomena that are results of the (strategic) behaviour of traders, i.e. that can not be reproduced in models without making behavioural assumptions, and those phenomena that can be reproduced without these assumptions and thus may be regarded as results of the market structure instead of strategic acts.

3 Methods

My research consists of both empirical analysis of data, construction of models and running computer simulations as well as analytical studies of the models. An important part of the empirical work was creating programs that make it possible to analyse the empirical data. This involves "cleaning" the data, in order to measure the variables of our interest. In case of the limit order book data this also involves constructing programs that re-build the entire order flow, practically regenerating all micro processes in the market. The empirical analysis of stock market data is based on methods used in statistical physics. To better understand the empirical findings, throughout the work I applied both multi agent modeling and phenomenological modeling of stock markets. The multi agent models were tools to define the microscopic dynamics of markets in order to analyse the emerging macroscopic measures. On the other hand the phenomenological models were used to generate surrogate market data in order to test some of the hypotheses.

For the analysis and simulation of stock markets, I primarily used C programming language, together with MatLab and R statistical softwares.

4 New scientific results

1. I studied the dynamics and time scale dependence of cross-correlations between financial returns.

    - I showed that the financial return cross-correlations have changed to a large extent on all studied markets. The correlations grew stronger and simultaneously their maximum position moved towards zero time lag. These results show that the markets are in a phase of increasing efficiency, mainly due to the spread of financial informatics and increased speed of information processing in the period studied; a sign of the changing aggregate behaviour of market participants due to change in market mechanisms, not to human nature. [1].
    - I analysed the dependence of equal time financial correlations on the Δt sampling timescale: For small Δt the correlations are much weaker than the asymptotic correlations, which are only reached on sampling time scales of a few hours (Epps effect).

      I showed the weakness of prior explanations given for the Epps effect, relying on the asynchronicity of price changes. I showed that the Epps curves measured for different time periods can be scaled by their asymptotic value leading to a collapse of the curves, while scaling with trading activity does not lead to data collapse [3].

      I gave the relation between the correlations measured on different sampling time scales. With the method I can determine the complete Epps curve, by using the correlations and their decay measured on the shortest meaningful time scale in the system. I showed that the characteristic time of the Epps effect is connected to the reaction time of human traders explaining why it does not scale with trading activity [4].

2. I gave a method to accurately estimate correlations between asynchronous signals. I presented a method to estimate correlations without applying long time windows and hereby worsening the statistics. The method is based on a decomposition of the correlations of data cumulated over a long window, with a generalisation

of the relation given to explain the Epps effect, using decay of lagged correlations as calculated from short window data. This increases the accuracy of the estimated correlation by almost an order of magnitude and decreases the necessary efforts of calculations both in real and computer experiments [8].

3. I analysed limit order book data from the London Stock Exchange around large intra-day price changes.

   - I studied the volatility, the bid-ask spread, the bid-ask imbalance, the number of queuing orders in the book, the activity of traders, the relative number of the different types of orders. I found that the measures a large variation, with a peak at the moment of the large price change. The relaxations of these measures after the variation is very slow, when fitted by a power law they show an exponent ≈ 0.4 for most cases. Specifically I found that the volatility and the bid-ask spread increase high above their normal value and exhibit power law relaxations; the bid-ask imbalance varies strongly, exhibiting slow relaxation; the number of queuing orders vary and exhibit slow relaxation with very different dynamics on the two sides of the book; the activity of traders increases, this can be seen in the strong increase in the number and volume of limit orders placed and canceled; these measures also exhibit power law relaxations with exponents ≈ 0.4. Studying the relative number of the different types of orders (that can also be regarded as a measure for the stability of trading strategies) I did not find strong variations suggesting that there is an increase in the entire activity of market processes and not a change in the strategic behaviour of traders. I studied the distribution of the number of unoccupied price levels close to the best orders (gap). My results support the theory of large price changes being caused by low liquidity periods, i.e., periods when there is a large number of unoccupied adjacent price levels close to the best offers: I found that the gap structure of the limit order book is different in pre-event periods from that in normal market periods [9].

- I constructed a zero intelligence, deposition-like model to mimic the order flow on a double auction market. I studied the stable dynamics of the model and analysed the effects of large price jumps. I found that the model is able to reproduce qualitatively the slow, power law decay of the volatility and the bid-ask spread, as found in empirical data. The model system exhibits slow relaxations, with an exponent slightly larger than in the case of real markets. This suggests that though the relaxation in real markets is somewhat slower than in the zero intelligence model, the main features of the relaxation can be reproduced without the assumption of strategic behaviour. I gave an analytic form of the relaxations of the bid-ask spread in the model for a limit case and for short times in the general case [9].

4. I constructed a multi agent model of a double auction stock market in order to analyse the effect of information on the performance of the trading agents and on trading efficiency. In the model I defined information as the ability to predict future movements of the stock prices through the dividend process. The simulations showed that information does not necessarily have positive effects on the performance, i.e., while traders having no information gain the market average, those with medium amount of information perform clearly under the market average and only the most informed ("insiders") are able to beat the market. I found that the simulated market reproduces the main stylized facts of real markets qualitatively and shows informational efficiency. I introduced the possibility of changing between two strategies for traders performing under the market average. The possible strategies were: (1) use their forecasting ability, (fundamentalist strategy) or (2) follow market trends (chartist strategy). The results showed that the traders with the most information stick to the fundamentalist strategy making use of their information, while the less informed traders bounce between the two types of strategies [2, 5, 6, 7], supporting the result that partial information is not necessarily and always an asset.

References

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