Agent-based simulation of a double-auction market with heterogeneously informed agents

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Abstract: We study the effect of inhomogenous information on a simulated double auction stock market. We find a non monotonic increase of net returns of traders as a function of information levels. Particularly traders with high levels of information (insiders) always beat the market but traders with small and average amounts of information perform worse than the market index, i.e. in the long run they get smaller returns than a trader putting random orders. Our results are in good agreement with experiments carried out by two of us in Innsbruck [1]. The simulations reproduce many stylized facts of stock markets, such as fast decay of autocorrelation of returns, volatility clustering and fat-tailed distribution of returns. These results have an important message for everyday life. They can give a possible explanation why on average professional fund managers perform worse than the market index.

Key Words: Asymmetric information, value of information, agent-based models, experimental economics

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1 Introduction

In everyday life it is usually understood that information is one of the most important assets. In the case of financial markets being informed is considered the only way of achieving returns above the average. In this paper we study the case in which there are several levels of information in a double auction stock market.

Based on experiments exploring the effect of heterogenous information of traders carried out with real human subjects we introduce computer simulations showing similar results. In the case of several levels of information, we found that having more information is not necessarily an advantage. In fact the average informed show worse results than random traders. However being among the best informed (being an insider) is surely an advantage.

Our experimental results combined with simulational results could explain why professional fund managers in many cases perform worse on the long run than the market [2].

The paper is structured as follows: in Section 2 we summarize experimental results; Section 3 contains the details of the simulations; our results can be found in Section 4. Summary and outlook are presented in Section 5.

2 Outline of Experiments

Experiments were carried out at the University of Innsbruck in 2004 with the participation of business students. In each session on a double auction market nine subjects with different forecasting abilities were trading the stocks of a virtual company. To reduce statistical errors the experiments were repeated seven times with different subjects.

2.1 Settings of the Experiments

The architecture of the experimental market was a continuous double auction with limit orders. In the market a risky asset (stock) and a risk free bond (cash) could be traded. Any time, traders could enter a new limit order to the book or accept someone's limit order (realising a market order). The volume in trades was fixed to one share. At the beginning of the experiment all traders had the same wealth: 40 stocks (each worth 40 units in the beginning) and 1600 units in cash. The experiment consisted of 30 periods each lasting 100 trading seconds. At the beginning of each period new information was delivered to the traders depending on their horizon of forecasting ability as will be discussed in Section

2.2. At the end of each period a risk free interest rate was payed on the cash held by the traders and dividends were paid based on the shares owned. The dividend process was generated in advance before the experiment and the same process was used for all runs of the experiment. The dividend process, $D(t)$, was a random walk with Gaussian steps.

2.2 Information

To value the shares, traders on the market get information about future dividends. Before the start of the experiment an information level from one to nine (*I1,…,I9*) is associated with each trader. There is one trader for each information level and this is public knowledge. The different levels of information correspond to different lengths of windows in which one can predict future dividends. Trader *I1* knows the dividend for the end of the current period, trader *I2* knows the dividends for the current and the next period, …, trader *I9* for the current and the next eight periods [1].
The information that traders obtain is the conditional present value of the stock conditioned on the forecasting horizon ($E(V|I_{j,k})$). This is determined by Gordon's formula, for the conditional average in period k for the trader with information level j (Ij), where V denotes the value:

$$E(V|I_{j,k}) = \frac{D(k+j-1)}{(1+r_e)^{j-2} r_e} + \sum_{i=k}^{k+j-2} \frac{D(i)}{(1+r_e)^{i-k}}, \tag{1}$$

where r_e is the risk adjusted interest rate ($E(\cdots)$ denotes the average).

2.3 Results of the Experiments

The net return of traders compared to the market return as a function of the information level can be seen in Fig. 1. One can verify that the returns do not at all grow monotonically with increasing information. Traders having the first five levels of information do not outperform the average (in fact some of them statistically relevantly underperform) and only the best informed traders (insiders) are able to outperform the market [1].

Testing the experimental results for well known empirical stylized [3] facts it was found that the markets reproduced many properties of real world markets, such as fast decay of autocorrelation of returns, volatility clustering, fat tail distribution of returns [4].

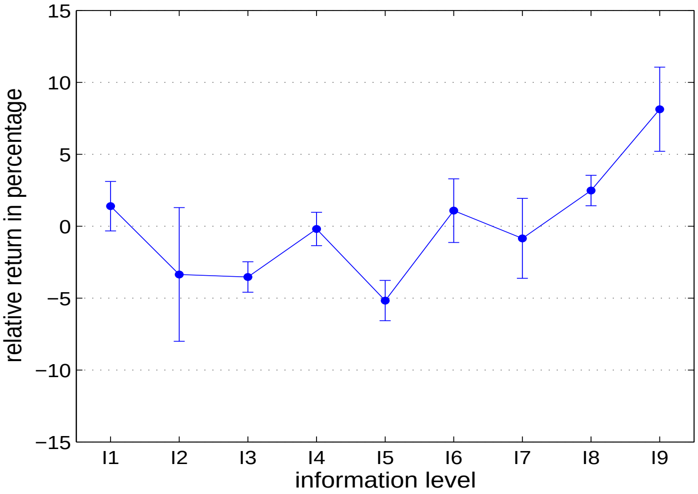

Figure 1: Results of experiments. Return of traders relative to the market in percentage, as a function of the information. The returns are a non–monotonic function of information.

3 The simulations

We carried out computer simulations to numerically check the results of the experiments. The simulations were run using MatLab programming language.

3.1 The market mechanism

In the simulation we programmed a double auction trading mechanism with a book containing the bid and ask orders. The simulational setup (length of trading, initial conditions, volume of trades, informational setup) was very similar to the experimental setup, hence we only mention a few characteristics. We implemented ten agents with different levels of information going from *I0* to *I9*, and with the possibility of using different trading strategies as will be discussed in details in Section 3.2 and Section 3.3.
The risk free interest rate was $r_f = 0.001$, the risk adjusted interest rate $r_e = 0.005$. The dividend process was determined before the beginning of the market session as a random walk of Gaussian steps:

$$D(i) = D(i-1) + \frac{0.2}{30} N(0,1). \tag{2}$$

with $D(0) = 0.2$, where $N(0,1)$ is a normal distribution with zero mean and unit variance. At the beginning of each period agents submit orders according to their idea of the value of stocks. Then in every second, one trader is chosen randomly who either accepts a limit order from the book (gives a market order) or puts a new limit order to the book. At the end of each period the book is cleared. We also carried out simulations without clearing the book and found that the clearing process does not make much difference in the results.

3.2 Information

Overall we implemented ten levels of information, a completely uninformed trader (random trader) (*I0*) and nine informed traders with different levels of information from *I1* to *I9*, where agent *Ij* has information of the dividends for the end of the current period and of $(j-1)$ oncoming periods (forecasting ability). The information received by traders was the present value of the stock conditional on the basis of their forecasting ability. This was determined by Gordon's formula (Eq. 1).

3.3 Trading strategies

Since we do not have exact information on how traders in real world and in the experiments use their information, we gave the possibility to simulated traders to strictly apply the fundamental information they get (*fundamentalists*), not to take any information in account except the current price, i.e. trade randomly (*random traders*) or to look at other pieces of information such as trends (*chartists*). In this paper we show results for the case of fundamentalist and random traders, these strategies are described below. The details of the trading strategies and order putting mechanisms can be found on the webpage: *http://www.phy.bme.hu/˜bence*

3.3.1 Fundamentalists

Fundamentalist traders strictly believe the information they received. If they find an *ask order* with a price lower or a *bid order* with a price higher than their estimated present value, i.e. $E(V|I_{j,k})$, they accept the limit order, otherwise they put a new limit order between the former best bid and best ask prices.

3.3.2 Random traders

Random traders (or commonly called noise traders) put orders randomly. With probability *0.5* they put an ask (bid) order slightly higher (lower) than the current price.

4 Results

As main topic, in our simulations we studied the effect of information on the performance of agents throughout the market session. We also analysed the results from the point of view of stylized facts of stock markets. In order to reduce statistical errors we averaged our results for 100 different runs of the simulation.

4.1 Final wealth as a function of information

Fig. 2 shows the return as a function of information level of agents. The results can be seen in percentage based on the market return similarly to Fig. 1. One can see that the trend of the figure is similar to the one obtained in the experiments. Traders with no fundamental information at all (*I0*), trading randomly are able to get the market return and traders with high amounts of information can outperform the market. However agents with small and average amount of information perform clearly worse than the uninformed.

The significance of this result will be further explained in Section 5.

4.2 Stylized facts

Since in the case of market simulations one aims to model behaviour and phenomena which hold in real world markets as well, we studied some attributes which are well known from existing markets, i.e. empirically observed stylized facts. Usually the three main empirical properties of real world markets are the fast decay of the autocorrelation of returns, the slow decay of the autocorrelation of absolute returns (volatility clustering) and the fat tail of the distribution of returns.

We analysed the results of our simulations from the point of view of these common facts. Fig 3 shows the autocorrelation functions of returns (circles and lines) and of absolute returns (dots and lines). The noise level of the computations is also included in the plot (straight lines). One can see that the autocorrelation of returns decays fast under the

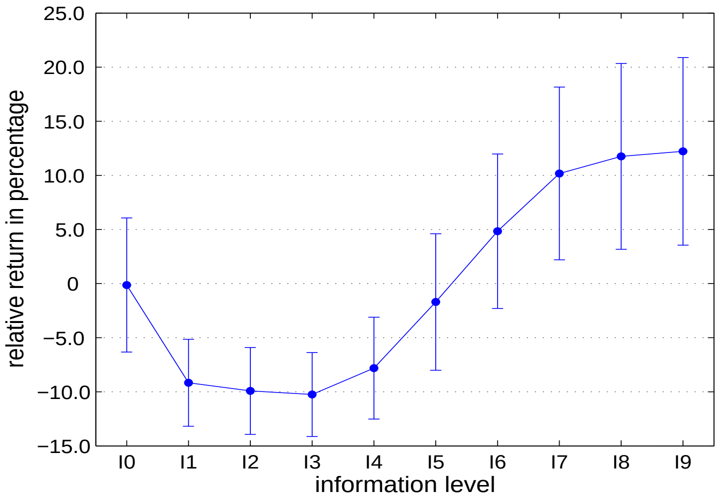

Figure 2: Results of simulations. Returns of traders relative to the market in percentage, as a function of information. One can see that having average level of information is not necessarily an advantage.

noise level (with an overshoot for small lags as it is usual in real world markets too), thus there is no long time correlation in price changes. On the other hand the autocorrelation of absolute returns decays slowly showing the fact that big price changes tend to cluster (volatility clustering). (A slight even–odd oscillation is visible in the autocorrelation of absolute returns, this is an artifact of our simulation process, there are many cases when the intertrade time is two simulation steps, resulting in this oscillation.) Studying markets with only random agents trading we found the same effect of volatility clustering thus we can state that it is an effect due mostly to the double auction trading mechanism as has been shown before in [5].

Figure 4 shows the empirical complementary cumulative distribution function of the absolute returns (dots) and for comparison the same distribution function for a series of the same length of normally distributed variables with the same standard deviation as the series of absolute returns (solid line). It can be clearly seen that the cumulative distribution function of absolute returns is a fatter tail distribution than the Gaussian as it is well known in real markets. Running the Jarque–Bera test we can surely rule out the normality of the distribution of the absolute returns.

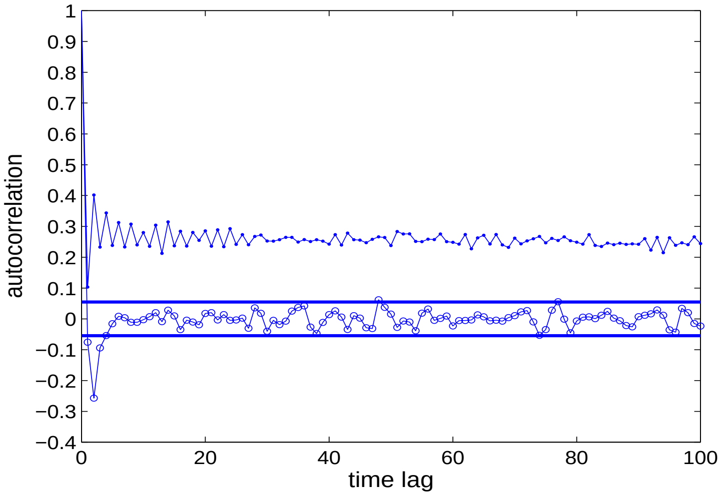

Figure 3: Autocorrelation functions of returns (circles and lines) and absolute returns (dots and lines) and the noise level (solid lines). Autocorrelation of returns decays fast under the noise level while autocorrelation of absolute returns decays very slowly, showing the clustering of volatility.

5 Summary and Outlook

In this paper we presented a model of heterogenously informed traders on a double auction stock market. We focused on the effect of information on the performance of traders. Similarly to experiments carried out with human subjects introduced in Section 2, we built a simulation platform running a double auction market mechanism with traders having different forecasting horizons.

The results of the simulation show a non-trivial dependence of agents' returns on the amount of information accessible to them. While highly informed traders (insiders) can achieve higher returns than the market, this is not true for average informed agents. We found that for small and average levels of information (the first 5 levels out of nine) there is a negative effect compared to the uninformed trader. Checking for stylized facts we found evidence for fast decay of autocorrelation of returns, volatility clustering and fat tailed distribution of returns.

Our results on the information dependence of returns have an important impact on everyday life. It is well known that most of the professional fund managers on stock markets perform worse on the long run than the market itself, i.e. they get lower returns than

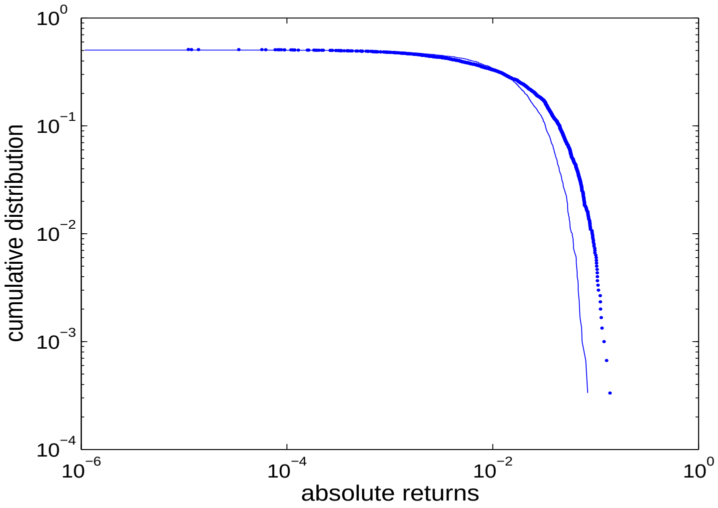

Figure 4: The empirical complementary cumulative distribution function of the absolute returns (dots) and for comparison the same distribution function for a series of the same length of normally distributed variables with the same standard deviation as the series of absolute returns (solid line). One can see that the distribution of absolute returns is a fatter tail distribution than the Gaussian.

a random trader would get in the same period, see e.g. [2]. The possible cause for this bad performance can be seen from our results: professional fund managers have a lot of information but mainly those that are available to every actor on the market. They mostly fit into the middle of our curve on Fig. 2, they are averagely informed, a trader taking random decisions can easily outperform them receiving the market return. The reason for this behaviour can be interpreted in the following way: traders having no forecasting ability trade randomly and can not be exploited by other traders, on the long run they get the market return. On the other hand traders having short and average forecasting horizon but believing the information they own, can be exploited by better informed traders, insiders.

Of course the behaviour of real world traders is much more complicated than the ones implemented in our simulations, e.g. they have the possibility of switching between stocks or sectors whereas in our experimental and simulational platform only one stock was present. Nevertheless the non-monotonic behaviour of Fig. 1 and Fig. 2 suggests an explanation for the low average performance of actively managed funds.

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