Artificial Software Agents on Thin Double Auction Markets -
A Human Trader Experiment

Jens Grossklags
University of California at Berkeley
School of Information Mgt. & Systems
102 South Hall
94720 Berkeley, CA, USA
jensg@sims.berkeley.edu

Carsten Schmidt
Max-Planck Institute for Research
into Economic Systems
Kahlaische Str. 10
07745 Jena, Germany
cschmidt@mpiew-jena.mpg.de

Abstract

This paper studies how software agents influence the market behavior of human traders. Software agents with a passive arbitrage seeking strategy are introduced in a double auction market experiment with human subjects in the laboratory. As a treatment variable, the influence of information on the existence of software agents is investigated. We found that common knowledge about the presence of software agents triggers more efficient market prices when the programmed strategy was employed whereas an effect of the information condition on behavioral variables could not be observed. Surprisingly, the introduction of software agents results in lower market efficiency in the no information treatment when compared to the baseline treatment without software agents.

1. Introduction

One exemplary application where humans and software agents participate alike is eBay [Ockenfels and Roth, 2002]. The auction format used by eBay is an open bid second price auction with a fixed ending rule. In this situation bidders have a strategic incentive to delay their bids [Roth and Ockenfels, 2002] and to bid at the very end of the auction, so-called sniping. Most of the bidders place their bid using eBay's graphical user interface. Lately services such as esnipe and auctionblitz[1] have offered to place a bid at the very last minute on the bidder's behalf. This automated bidding supports human bidders in a routine task that is thus performed more precisely. In this example, the software agent exploits human shortcomings (bidders not recognizing the strategic incentives of late bidding) and does the job without the proneness to error of human interaction with software systems.

In a different environment, we are posing the following questions that might be stated in the eBay context as well: How do software agents influence the market behavior of human traders? And does individual knowledge about software agents influence human behavior and the market outcome?

The intention of this study is to concentrate on a stylized, controlled environment and to understand and disentangle the economic and psychological drivers of human-agent interaction. To our knowledge we here present the first

study explicitly focusing on the impact of software agents on human behavior in a controlled economic experiment.

The experiment presented in this paper relies on a market institution quite common in financial markets - the continuous double auction (CDA). In this auction type sellers and buyers may submit bids and asks simultaneously and asynchronously, and in continuous time. The framework that allows software agents to interact with such a market is described in Grossklags *et al.* [2000], where a simulation exclusively with software agents was conducted.

In the present paper, human traders are introduced into this framework. To facilitate an informed experimental design, we conducted first pilot experiments in June 2001 featuring the simultaneous participation of human traders and software agents to decide which agent trading strategy to select for the human-agent interaction experiment. We were searching for a strategy that is easy to interpret and nevertheless has high importance for financial markets. Such a natural and financially relevant candidate to explore human-agent interaction is the *arbitrageur*. Its strategy is to constantly scan the market in order to exploit risk free profit opportunities, resulting from price variations of a contract in different markets. From a behavioral point of view, the *arbitrageur* can be described as a passive, rather parasitic strategy sitting in the background and earning profits from the imperfections of other traders. In the following sections, in order to distinguish human traders from software agents acting as traders as well, the term "traders" will be used for human participants and the term "agents" for software participants.

The main contribution of the paper is the introduction of an information condition into a human-agent experiment. Two treatments were conducted with experimental parameters held constant except for the information available about the software agents: in one treatment the participation of the software agent was made common knowledge, and in the other treatment subjects were not informed about the existence of software agents. In addition, the data is compared to a third treatment (which we call baseline treatment) without software agents or information about the presence or absence of software agents.

The introduction of the information condition allows us to form a central hypothesis about the reactions that can be expected from human traders when information on software agents is provided. Human traders suffer from the uncertainty about the agents' capabilities, e.g., their speed in

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[1] http://www.esnipe.com, www.auctionblitz.com

calculating strategies and in processing transactions. This uncertainty might lead agents to crowd out humans from the market. It is a strong hypothesis that would require human traders not to trade at all when information about the existence of software agents is available. However, in the context of the double auction market institution, traders cannot observe if a particular trade is done with a human or a robot. Thus, an alternative hypothesis can be formulated according to which humans compare themselves with other human traders only and neglect the existence of software traders. This hypothesis would predict no difference in human behavior when information is provided. Further hypothesis are stated in section 2.3.

Closely related to our experiment, Das *et al.* [2001] conducted an experimental series where human traders interacted with software agents. They followed the design proposed by Smith [1962] where participants were assigned fixed roles as either buyer (submitting only bids) or seller (submitting only asks) and received a private valuation (cost) for the traded good as a buyer (seller). In their study the experimental conditions of supply and demand were held constant over several successive trading periods and were then exposed to a random shock that changed market parameters. Experimental sessions involved 6 human traders and 6 agents. In addition, a baseline session with 12 human traders was run. Two types of agents were used that applied either a modified Zero-Intelligence-Plus strategy [Gode and Sunder, 1993; Cliff and Bruten, 1997] or a modified Gjerstad-Dickhaut algorithm [Gjerstad and Dickhaut, 1998].

While in general the human-agent markets in Das *et al.* [2001] showed convergence to the predicted equilibrium, their markets already indicated interesting market anomalies that were, however, not analyzed any further. For example, the price patterns showed a strong scalloping behavior in comparison to pure human or agent markets. Markets tended to have a lopsided character in which either buyers consistently exploited sellers, or vice versa. The agent instances reaped average profits well above those of human traders. However, the experiments also showed that in human-agent environments artificial agents can be subject to exploitation by humans. In their experiment, between 30 and 50 percent of the trades were done between agents and human traders. A further direct comparison of findings seems difficult since Das *et al.* [2001] only report selected data on their markets that is directed towards their particular study objective: the comparison of the profits of agents and humans.

Compared to Das *et al.* [2001], the present paper introduces software agents into the more complex environment of a continuous double auction market. This includes the following: a trader acts both as a buyer and seller; information about the fundamental value of the securities changes in every round; orders allow for multiple units of a specific contract; and the market institution provides no spread improvement rule. We believe, that this scenario offers a more natural environment for financial trading than the one-sided markets described above, and enables us to better observe behavioral factors that influence human trading.

The main results of our study are as follows. We find that agents do not crowd out human traders in the treatment with common knowledge on software agents. Instead, common knowledge on the presence of software agents has a significantly positive effect on human traders' ability to converge to equilibrium in the presence of the *arbitrageur* agent. Furthermore, intuition would suggest a higher efficiency in an environment with software agents when compared to no software agents. Surprisingly, when compared to the baseline treatment the introduction of an arbitrage seeking type of software agent results in lower market efficiency in the no information treatment.

In the next section the experimental design is presented, including the market and the software agents' strategy. The experimental results are described in Section 3. Related work is discussed in Section 4. Finally, concluding remarks are given and open research questions for further exploration are outlined in Section 5.

2. Experimental Design

2.1. Market Institution and Information

The market institution was designed by using a continuous double auction, i.e. an auction in which sellers and buyers may submit bids and asks simultaneously and asynchronously. More precisely, sellers and buyers are free to accept bids and asks at any time during the experiment. CDA market designs are very popular among financial markets, both real and virtual, and are described as having the remarkable quality of being fast and efficient [Friedman, 1984 & 1993]. In contrast to markets where the issue of securities is organized by an initial public offering, this is implemented on this particular market via a so-called bundle mechanism and therefore resembles closely the design of the Iowa Electronic Markets [Forsythe *et al.*, 1992 & 1999].[2] The bundle consisted of a standardized unit-portfolio where the sum of each different contract carries a fixed price. This bundle can be bought from or sold to the bank at any time and any quantity. The market foresaw three valid operations: (1) posting market orders (bids implement buying orders and asks implement selling orders), (2) deleting own market orders, and (3) buying/selling bundles at the bank. Submitted orders remained open until they were traded, or the experiment ended. No restrictions to the posted prices were made.

The market implements an American futures market, where contracts can be traded on some kind of event. The outcome of the event determines, depending on the market rules, the payoff of the different contracts. For the experiment described, a payoff scheme similar to "vote share" election markets has been used, where each contract pays off a percentage of the total bundle. The experiment was conducted with a market that contained five contracts each representing one firm. Three contracts represented relatively more valuable firms (contracts A, B, and C) and

two representing relatively less valuable firms (contracts D and E).

The value of each different contract was characterized by a strength measure given in points. For example, if the firm is doing well it will gain points, while if it performs poorly it will lose points. Furthermore, the strength points provide an indicator of its relative performance compared to the other contracts in the bundle. This implies that an increase in points in one contract results in a proportional decrease of the equilibrium price of the other contracts on the market as well. The equilibrium price equals the fundamental value of a contract and can be calculated by dividing the points of a contract by the sum of points of all different contracts in the market multiplied by 100.

During the experiment, the participants received the information on their computer screens. Initially, all participants were given the same information in the instructions and a trading time of three minutes. Afterwards, the information was sent by the following schedule: reception of private information on the contracts' points, 4 minutes time of trading, reception of public information, and 2 minutes time of trading. This schedule was repeated 12 times. Altogether the market was open for 75 minutes and each subject received 13 public and 12 private information messages.

A storyboard was designed in order to provide a constant environment for all sessions and treatments (Figure 1 presents the equilibrium price over time for each of the 5 contracts). It was determined by the experimenters with a rolling dice. The storyboard describes the change of points and the corresponding fundamental value of the five different contracts, and the private information points distributed to the six human traders' roles. Thus, each human trader role, say for example trader number 2, was assigned the same information throughout all sessions. For the sake of simplicity, only one contract changed its points in each round, so that if the points of contract A were going to change in the first round the other contracts didn't change in points. Still, this scenario implies a change of the fundamental value of all the different contracts in the market. Each of the six traders in this storyboard received different private information about the change in points. The mean of all private information sent to the traders was equal to the actual change. This true change was made available to the traders with the public information.

2.2. Programmed Trader

The market-agent interface (XML) and several implemented software agents (in Java) are described in detail in Grossklags *et al.* [2000]. For the purpose of Grossklags *et al.* the software agents were selected under the premise of being pure and simple strategies, which resemble a real world analogy. A simulation tested the market-agent interface and pointed out strategies that are successful when competing with other software agents. For the present study we selected the *arbitrageur* agent because it is expected to be also profitable in a market experiment populated with human traders, and it employs a natural and financially relevant strategy. It is a software agent who constantly scans the market in order to exploit risk free profit opportunities, resulting from price variations of a contract in different markets. From a behavioral point of view, the *arbitrageur* can be described as having a passive, rather parasitic strategy sitting in the background and earning profits from the imperfection of other traders.

The aim of the *arbitrageur* agent is to profit from arbitrage opportunities that arise because of the difference between the market price and bank price. In detail, the *arbitrageur* exploits the difference between the market price of a bundle - more correctly, the bids and the asks of each single contract forming the bundle - and the bank price for the same bundle, buying the bundle from whomever sells it at the lowest price (the bank or the market) and reselling it to whoever is ready to buy it at the highest price (the bank or the market). When the agent is able to conduct all transactions, in the experiment this includes 5 market transactions and one bank transaction, a guaranteed profit can be achieved.

The *arbitrageur* continuously scans the market and applies the following algorithm:
- if $\sum Ask_{Min}[Stock_i] < 100\ ECU$ [3], then buy unit-portfolios from the market and resell them to the bank as a bundle
- if any combination of stocks (one stock alone, two stocks, three stocks, etc.) is requested at a price, which exceeds 100 ECU, then buy a bundle from the bank, split the bundle and sell the stocks separately to the market.

The simulation in Grossklags *et al.* [2000] displayed that in the sample environment with 11 different programmed strategies the *arbitrageur* was not in every case able to complete the whole set of transactions necessary in order to gain a sure profit and avoid risk. Still in the simulation the *arbitrageur* agent gained on average positive payoffs.

2.3. Experimental Procedure and Hypothesis

The experiment is designed to separate the influences of the programmed strategy and information on the participation of software agents. Therefore, the agent treatment has been run with and without information on software agents. In addition, a baseline treatment with human traders only has been run. For this treatment no information about software agents was given out.[4] Each session consisted of a market with 6 human participants and 6 streams of information. In the *arbitrageur* treatment the software agent was used in addition to the 6 human traders. The passive trading strategy *arbitrageur* does not use point information on individual contracts in order to apply its strategy (only market prices and quantities). Thus, we didn't provide him with point information, but all other information available on the market. Apart from the presence or absence of software agents and the provision of information about the existence of software agents there was no other difference between the individual markets. Altogether 18 sessions have been run with 108 *different*

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human participants and 12 programmed traders and thus six independent observations for each treatment were collected.

The human participants were recruited among students of the University of Jena, Germany. The laboratory sessions took place in June 2002 in the experimental laboratory of the Max-Planck Institute for Research into Economic Systems. In the experiment software agents face the same budget constraint as human traders do. Each participant - traders as well as agents – was given an initial endowment of 100,000 ECU = 10 US$. At the beginning of the experiment the instructions were available on the computer screen and read out loud by the experimenter (for complete instructions see Grossklags and Schmidt [2002]). A demonstration of the trading screen including sample transactions for all three valid market operations was provided with a video projector.

Two hypotheses with regards to the influence of software agents on human traders were formulated. First, a crowding out of human traders might be predicted in the treatment with public information on software agents. This hypothesis predicts that human traders will not trade at all when information about the existence of software agents is available.

Second, software agents are expected to improve market efficiency. They follow predefined rules and do not make mistakes with respect to their algorithm. In addition, software agents can process more data in a given time span and interact faster with the software interface than human traders are able to interact with the graphical user interface. For the evaluation of this hypothesis efficiency deviations from the equilibrium price and volatility measures of the different treatments are evaluated.

3. Results

In a first step the payoffs of human traders and software agents are compared. It seems important to state that software agents do not make losses on average. Otherwise agents just distribute money to human traders and the experimenter loses control. A zero sum market has been used; therefore each different agent should at least regain the invested capital of 100,000 ECU on average. Out of 12 sessions, agents achieved positive payoffs in 11 cases. One *arbitrageur* agent made a zero profit due to missing arbitrage possibilities. Profits of the agents differed significantly from zero (see Table 1): on average the *arbitrageur* agents made 0.3% profits during the 75 minutes period of time.

Human traders did lose this percentage in the corresponding treatments but this effect is not significantly different from zero profits (T = -0.963; p < 0.33). Furthermore the variability of the software agents' profits is significantly lower when compared to human traders monetary payoffs (F = 3.596; P < 0.000).

Next behavioral variables are analyzed. The first aspects are the number of trades and portfolio restructuring activities of human traders and agents. In the following average values of the 6 independent observations for each treatment are compared and if not otherwise noted a permutation test is used in order to test for statistically significant differences. For each of the agent treatments the number of trades is not significantly different from the baseline treatment. The average number of trades declines in the *arbitrageur* treatment when compared to the baseline treatment but this effect is not significant what can be attributed to a high variability of the individual sessions' averages.

It can be observed that trades between agents and human participants crowd out human-to-human transactions. The number of human-to-human transactions is significantly lower in the treatments involving a software agent when compared to the baseline treatment. The percentage of human-to-agent (h2a) trades in the *arbitrageur* regime is 16% in the no information and 22% in the information treatment. The information on software agents does not have a significant impact with respect to human portfolio restructuring (Table 1).

On the individual level we observed 4 human traders, each of them in a different session, who did not trade at all (even though they had to stay for the complete experiment). This behavior could be observed two times in both the information and the no information treatment. Thus, a crowding out of human trades by the presence of information on software agents could not be confirmed and this hypothesis was not validated.

Result 1: *There is no crowding out of human traders when public information on software agents is available.*

Altogether five different contracts were available for trading. During each round informational changes in points were given to the participants for one contract type only. The market design implies that informational changes in one contract result in changes of the equilibrium price of all other contracts as well. Due to the random character of the storyboard such point information for the contract B was first provided after 69 minutes of the experiment; that is, in the last period only. Note that trading a contract without direct informational change requires a further level of reasoning, e.g. if the points and thus also the price of contract A change, this implies that the price of contract B, C, D, and E change as well. Therefore, we regard the time when trades and prices in all five different contracts are first realized as a proxy for trader's rationality. The baseline treatment provides prices for all different contracts after less than 10 minutes of the experiment. In the *arbitrageur* regime prices for all different contracts are available roughly 25 minutes after the start of the experiment. This difference between the *arbitrageur* and the baseline treatment is significant. Behavioral differences in this context could not be observed with respect to the information conditions.

Result 2: *With respect to behavioral variables, we observed a difference in the first time when prices for all 5 different contracts were realized. We infer that the introduction of the passive agent does not guide human traders to rationalize the connection between the 5 different contracts.*

In the following the focus of this paper will shift to explore several efficiency measures. In a first step arbitrage opportunities between the market and the bank are

evaluated. The bank promises during the experiment to buy and to sell the unit portfolio for a fixed price of 100 ECU. Therefore, the aggregated price of one unit of each different contract on the market should be 100; lower market prices are an indicator for undervaluation, and higher market prices for overvaluation. The *arbitrageur* agent explicitly scans the market for immediate arbitrage opportunities. It can be suspected that the market price of a bundle should be close to 100 in this regime. Table 1 provides evidence that on average in the *arbitrageur* regime the unit portfolio is not significantly different from 100. The information provided in the private information phases allows calculating the equilibrium price of a contract from the six different pieces of information provided to six traders. During the public information phase the points allowed to calculate the fundamental value of the contracts directly. Price deviations from equilibrium (fundamental value) will be considered as inefficiencies. When calculating the deviation of the market price from equilibrium, we apply normalization of prices to account for differences in contract prices. The intuitive calculation of the average deviation for a trading round (e.g., session or information period) is presented in (1).

$$Dev = \frac{\sum_{\#Trades}\left(1 - \frac{fundamental\ value}{market\ price}\right)}{\#Trades_{Rounds}} \qquad (1)$$

With respect to the deviation measure it can be observed that the baseline and the *arbitrageur* no information treatments differ significantly from the *arbitrageur* information treatment. This effect is more pronounced in earlier rounds. We conclude that the information condition has a significant effect on the human traders in case of the passive agent: human participants are observed to trade closer to equilibrium in the information condition.

Result 3: *Information condition: The public information on the presence of software agents has a significant positive effect on human traders' ability to converge to equilibrium in the presence of the arbitrageur agent.*

To further explore the determinants of non-equilibrium trade we ran a GLS regression using the complete data including the baseline treatment. The treatment variables, time, and price are included in the regression to measure deviations from equilibrium trade. Significant negative signs imply trade closer to equilibrium.

The dependent variable deviation takes 0 in equilibrium and is larger when the deviation from the fundamental value is larger. Since deviations in each of the 18 sessions are likely to be correlated, and in a statistical sense are not strictly independent, an error components econometric model with the session as the random component is used. Table 2 reports the results. Confirming our discussion on deviation from equilibrium prices we find that deviations increase in the *arbitrageur* regime without information about the agents' presence. Deviations decline over time and are more pronounced in lower priced contracts. We attribute smaller deviations in later periods to learning and larger deviations for lower priced contracts to rounding of prices in the market.

Result 4: *Baseline treatment: Surprisingly, the introduction of software agents results in lower market efficiency in the no information treatment when compared to the baseline treatment.*

4. Related Work

Obvious examples where both human traders and software agents participate are to be found in financial markets. In the early '90s neural networks, genetic algorithms, fuzzy logics, chaos theory, and other approaches were applied to automate trading. It seems the hype has disappeared, and "black box" traders are managing rather small funds on Wall Street. The majority of funds are now managed by human traders that are supported by software aids filtering and aggregating information.[5] This can also be attributed to still open research questions about the impact of artificial traders in situations of market instability. Exemplary, Leland and Rubinstein [1988] and Varian [1998] discussed the role of artificial traders that followed 'price insensitive' strategies such as portfolio insurance that might have contributed to the 1987 stock market crash. Gennotte and Leland [1990] provide a rational expectations model that draws on these experiences and aim to explain financial instability and discontinuities.

Related research into experimental asset markets is vast in its dimensions and we will review only few results. Common to most market experiments is the incorporation of public as well as private information characteristics, for example, in Copeland and Friedman [1991], Forsythe and Lundholm [1990], and Plott and Sunder [1988]. In these experiments, trade is motivated by differences in both private information and private valuations. Further, Smith *et al.* [1988] and Peterson [1993] have undertaken pure common value markets. In these cases, traders are endowed with only public and no private information regarding the expected common value. These markets motivate market trading through a combination of different risk attitudes of the traders, and different expectations concerning the other traders' strategies.

Much work has also been done about automated agents in the context of electronic commerce. A good starting point on agent mediated electronic commerce can be found in Guttman *et al.* [1998]. Hereafter, the focus is on related work that is concerned about automated negotiation. In particular market-based approaches are reviewed, which provide a market institution and a set of rules to do the negotiation. In this context agents negotiate in a competitive environment, yet there are other approaches in the AI community, such as collaborative agents, that will not be reviewed here.

In the artificial intelligence community agent tournaments are conducted in an increasingly complex environment, see for example, the Trading Auction Competition (TAC) described by Wellman *et al.* [2001 & 2002]. In TAC agents arranged in groups of eight are

assigned the role of travel agents charged with the task of arranging and automatically shopping for trips. The challenging part for agents' design is to address the interdependence of the tasks necessary to complete a trip, and the ability to reason about others strategies in a thin market of automated agents and in a continuous timeframe.

In experimental economics community work on programmed strategies has also been done by conducting tournaments [Abreu and Rubinstein, 1988; Rust *et al.*, 1994, Selten *et al.*, 1997]. Rust *et al.* report on the Santa Fe Double Auction tournament, where researchers were invited to submit software agents that compete on a CDA market against one another. The most successful strategy in this tournament can be described as rather parasitic: sitting in the background and exploiting the strategies of other agents. In addition, they report about an evolutionary tournament, where the percentage of agents was adjusted in accordance to the success of a strategy over time. Parallel to the tournament there has been a discussion on the lower bound of trading agents' intelligence to act similarly to human traders in a market institution [Gode and Sunder, 1993; Cliff and Bruten, 1997].

In the more expanding field of agent-based computational finance further multifarious work can be found. Lettau [1997] investigates how closely evolutionary (genetic algorithm) techniques can achieve the optimum in a purchase situation for a risky asset. Other early applications for these techniques are a genetic algorithm environment for learning to construct a test for general equilibrium in a foreign exchange market scenario [Arifovic, 1996], and a learning algorithm in Routledge [1994] that addresses investors' optimal choice in a repeated one-shot decision situation for a portfolio when costly information signals are available. Alternatively, approaches using neuronal network based agents as in Beltratti *et al.* [1996] can find valuable applications in decentralized price-finding institutions. A further starting-point for agents' design can be found in the economic mechanism design literature, see Varian [1995] for an introduction to this discipline.

5. Conclusion

This paper reports on an experiment where human subjects and software agents participate in a double auction market institution simultaneously. In this environment traders can buy and sell American futures. The experiment was conducted in a controlled laboratory environment, and six statistically independent observations for each treatment were collected. The experiment was designed to disentangle the effects of the introduction of software agents and the psychological effect of the public announcement about their presence. The main result is that human traders do not crowd out when the participation of software agents is made public. However, the results show that there is a significant decrease of human-to-human trades in the treatments including an *arbitrageur* when compared to the baseline treatment. Moreover, the public information on the presence of software agents has a significantly positive effect on human traders' ability to converge to equilibrium in the presence of the *arbitrageur* agent. Surprisingly, the

introduction of software agents results in lower market efficiency in the no information treatment when compared to the baseline treatment.

The focus of this research is to shed light on economic and psychological effects imposed on human beings when interacting with software agents in a competitive environment. The first studies conducted are to serve as a starting point to obtain a deeper insight in how to apply technically well studied software agents in an environment with bounded rational human beings. On a methodological level we are concerned with the rather high variability of individual session averages for efficiency and behavioral variables observed in this and other market experiments.

We feel confident that our design and the statistical analysis using the permutation test and random effects GLS regressions provide a good description of the underlying effects. Evidence on CDA markets relying on a single independent observation for each treatment should be treated carefully and may require further repetitions.

It can be observed that behavioral and economic effects can be attributed to different experimental conditions. Behavioral differences can be observed between agent sessions and the baseline treatment. More specifically, subjects start trading (all different contracts) at a later point in time in the presence of the *arbitrageur* agent when compared to the baseline treatment. The change in human behavior due to the introduction of a trading agent might be agent-strategy specific. An environment using more active agents might support human traders in starting trading at an earlier point in time. With respect to the information condition human traders are observed to act more efficiently in a market environment when information on software agents is available. This might be the most surprising result of the study since standard economic theory would predict no treatment effects. To generalize the results, the introduction of different types of agents in the current framework might be interesting. Further, it seems that commodity auction experiments with human traders and artificial agents might be a promising area of research as well.

6. Acknowledgements

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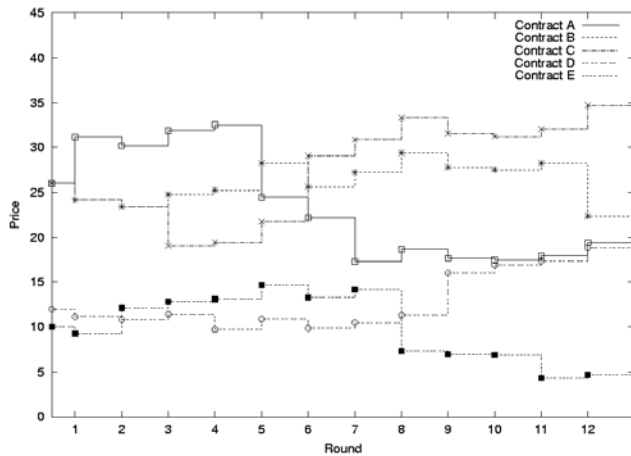
Appendix – Tabulated Results

Figure 1 Model of the fundamental value of each firms stock

		No Information	Information
	No Agent	Arbitrageur	Arbitrageur
Average Payoffs (in ECU)			
Software Agents	-	*100323	*100282
		(248.9)	(285.7)
Human Traders	100000	99946	99953
	(7447.5)	(5626.8)	(7469.9)

Number of Market Trades			
Total	141.7	108.2	119.2
	(34.8)	(71.9)	(73.0)
Human to Human (h2h)	141.7	91.2	92.5
	(34.7)	(64.2)	(34.5)
Human to Agent (h2a)	-	17.0	26.7
	-	(13.9)	(40.3)
Unit Portfolio at Market Prices			
Overall	97.82	102.11	99.61
	(5.23)	(5.39)	(3.52)
Rounds 1-6	106.70	108.52	104.17
	(5.87)	(11.95)	(2.43)
Rounds 7-12	90.73	98.63	97.96
	(8.34)	(2.86)	(3.32)
Time until Market Prices for all Contracts were Available			
Time in sec.	616.17	1556.50	1587.33
	(130.59)	(954.08)	(1031.80)
Time (% Total Experiment)	12.71%	34.59%	35.27%
Deviation from Fundamental Value			
Overall	0.21	0.31	0.17
	(0.05)	(0.22)	(0.02)
Round 1-6	0.17	0.27	0.13
	(0.08)	(0.28)	(0.02)
Round 7-12	0.24	0.33	0.21
	(0.03)	(0.22)	(0.04)
*** p<0.001; ** p < 0.01; * p < 0.1 t-test payoff<>100000			

Table 1 Summary of descriptive results, average of 6 sessions (standard deviation)

Overall Model Fit	
Number of Observations	2214
Number of Groups	18
Observations per Group Avg.	123.0
R2 (within)	0.025
R2 (between)	0.187
R2 (overall)	0.037

Parameter Estimates		
Independent Variables	Dependent Variable: Deviation	P > | z |
Constant	0.523	***
	(0.058)	
Arbitrageur, no information	0.141	*
	(0.067)	
Price	-0.017	***
	(0.002)	
(standard error)		
*** p<0.001; ** p < 0.01, * p < 0.05		

Table 2 Random-effects GLS regression