Exogenous Information and Endogenous Market Behavior with Artificial Learning Traders

Hidenori Kawamura†, Daisuke Kanehira†, Koichi Kurumatani‡, and Azuma Ohuchi†

†Graduate School of Engineering, Hokkaido University, Kita 13 Nishi 8, Kita-ku, Sapporo, Japan
{ kawamura, ohuchi}@complex.eng.hokudai.ac.jp

‡National Institute of Advanced Industrial Science and Technology, Aomi 2-41-6, Koto-ku, Tokyo, Japan
kurumatani@w-econ.org

Abstract

The relationship between macro behavior of the market and micro behavior of traders is very complex. Especially, the relationship between the information and interpretation of traders has not been studied yet. In this paper, we model the artificial market and adaptive trader agents with the abstract information, and clarify the emergent process of micro-macro behavior with traders' learning mechanism of the information. The learning and interpretation of trader is modeled by the translation from the information to the internal and external signals, which are used for trader as input signals to make a decision. Through several computer experiments based on such agent-based simulation, we confirm the micro-macro behavior between the artificial market and learning trader agents. In addition, to implement the simulation system, we used X-Economy system, which is a platform system for multi-agent Economics supplied in X-Economy project.

Introduction

What was happen in Tokyo stock exchange market? At noon in 16, April, 2001, the Imperial Household Agency of Japan had announced the possibility of pregnancy of the Crown Princess. Then, the stock prices of Japanese maternity goods companies had risen remarkably, such as the stock price of a certain company had been increased about 49 percent in a day (1). A month after, the Imperial Household Agency had officially announced the pregnancy of the Crown Princess, and the stock prices of maternity goods companies had remarkably risen again (2).

This phenomenon was observed twice, and it is mentioned that it was not obviously accidents. We know that the announce of pregnancy was essentially unrelated with worth of Japanese maternity goods companies, for example, everyone knows the birthrate of Japan has decreased every year. Therefore, it is clear that the announce of pregnancy effected trader psychology in Tokyo stock exchange, and many traders expected the rise of prices and required the stocks of these companies. This phenomenon is an evidence that information, which is generated in external environment, moreover, is not related with worth of stock, has the possibility to affect trader psychology and behavior of market.

How do we understand this phenomenon in the context of economics? The efficient market hypothesis (EMH) describes behavior of market as following summary(3).

- Each market participant of a financial market takes in very quickly and exactly all the information related to the movement of a market price, and uses it for price expectation.
- The market price that determined by the dealings between such market participants is reflecting properly all the relevant information that is available at present.
- Therefore, there is no room for a certain person to find out the new relation between a market price and the available information, and to become advantageous from other persons. That is, the movement of a market price becomes a random walk driven only by new information, and nobody can predict it.

According to the above, the EMH supposes the existence of universal relationship between information and interpretation, and the issue of information in the EMH is whether they can know the information or not. However, to understand the fact that the announces of pregnancy had remarkably risen the price of some companies, we are necessary to focus on the heterogeneity of relationship between the information and the interpretation. Although the information is naturally unrelated with the stock price, it has the potential to affect the market.

It is easy to consider the effectiveness of information if it apparently describes the worth of company like a business report, however, it is necessary to study the method to treat ambiguous information structure and behavior of market in order to understand economic systems profoundly. To understand relationship between information structure and macro-level behavior of market, we focus on learning process of information interpretation.

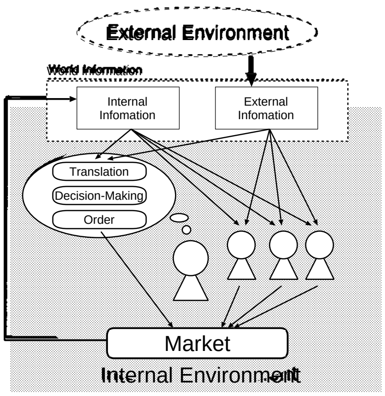


Figure 1: The model structure with trading agents, an artificial market, and the information.

In this paper, we assume the following simple scenario in the first step of our study. There is finite exogenous and endogenous information in the world, and endogenous interpretation of such information does not exist in advance. The behavior emerged from the activity of participants varies the market prices, and heterogeneous participants try to learn interpretation of information based on the change of price. Namely, we assume the model that interpretation of exodogenous and endogenous information is learned by the micro-macro feedback mechanism. The main purpose of this paper is to clarify learning mechanism of exdogenous information and effectiveness for market behavior with heterogeneous learning traders.

However, it is generally difficult for only theoretical approach to investigate the complex phenomena with a set of many adaptive and heterogeneous agents, therefore, we use computer simulations to realize the artificial market and traders with learning ability, namely, agent-based simulations(4)(5)(6)(7)(8).

To implement the experimental simulation system, we develop X-Economy system in X-Economy project which is the project to provide common agent libraries and a server for artificial market and economy (9).

The remain part of this paper is organized as follows. Section 2 describes the outline of our model, and Section 3 is related with the detail of decision-making and learning of the trading agents. Section 4 shows several experimental results, and the results are discussed in Section 5. Finally, Section 6 concludes this study.

Model

To clarify relationship between the macro behavior of market and the information structure, e.g., consisting of economic news, economic announcement of the government, behavior of economic index, the number of black spots of sun, and so on, we construct the artificial trading agents and the artificial market (see Fig. 1).

An artificial trading agent in this model has two kinds of simple properties, i.e., risky stock and risk-free asset. The worth of risky stock is changed with link to the market price, and the worth of risk-free asset is constant in this model. An agent makes either sell or buy orders of risky stock in each simulation time, and orders of all agents are gathered to the market. Each order consists of the volume and the price. If it is a sell order, the price means the lower limit of the sell price, and if it is a buy order, the price means the higher limit of the buy price. Then, the market contracts gathered sell and buy orders in the equilibrium price like the quantities of supply and demand are balanced. The motivation of each agent is only speculation, and in order to make a large profit, a trading agent tries to use the world information.

In the real world, there are infinite information that we can not know essential relationship with the real world, but many actual traders interpret and use information based on their subjectivity or expectation of what this information causes. To investigate effectiveness of such information, we model information as the abstract information which is represent by simply and clearly defined one, but it is noticed that the special meaning or effectiveness for decision-making of agents is not defined in advance. These are obtained by each agent through the learning process of macro-level behavior.

The abstract information consists of two types, i.e., the internal information and the external one. The internal information is closed in the model, and generated according to endogenous behavior of market price. Namely, it is merely reflective information of market price behavior. This internal information means the technical index calculated from the sequential data of the market price. In the real market, many traders use this type of information for the prediction of market price. All trading agents can know the change of past market price, and this internal information may represent the characteristic of dynamics of market price for traders to make a decision.

Another important information is the external one. This information is considered as an abstract of exogenous information coming from external environment. In the real world, there are infinite external information, and we can not know the relation with the essential worth of risky stock and this information. However, we often observe the phenomena that one external information affects the behavior of market price even if this information is not related with the essential worth of the stock. If the exogenous external information affects the decision-making of trading agents, this information becomes available for a trading agent to predict the decision-making of other agents.

To model the internal and external information, we adopt the world information model consisting of 11 bits. First three bits mean the external information. Concerning with the external information, we can not know the occasion of generation, the relation with the market price, and the effectiveness to the decision-making of other traders in the real world. Therefore, we simply model the external information generated as random noise one from the external of the system. This information is common among trading agents but it is not necessary true that all agents synchronously interpret it. We know this suppose of the model is too simple to represent the real economic system, but the main topic of this study is to clarify dynamics of relationship between exdogenous information and endogenous market behavior. If we assume huge information space to approach the real, it is difficult for a machine agent to learn its behavior in limited computer resource. Therefore, this simple model is suitable for the first step of analysys.

The external information, I_0, I_1, I_2 are defined as follows.

$$I_0, I_1, I_2 = RAND\{0,1\} \quad (1)$$

where, the function $RAND\{0,1\}$ returns the randomly selected integer number from 0 and 1. Namely, there are 2^3 patterns of external information in this model.

As the internal information, we define 8 bits $I_3, I_4, \ldots, I_{10}$ based on the past market price. Let the market price in the simulation time t be P_t, the middle periods moving average of P_t in 5 periods be $mmaP_t$, , the long periods moving average in 25 be $lmaP_t$, and the volume of contracted orders be V_t. The bits of internal information are defined as follows.

$$I_3 = \{1: \text{if } P_{t-1} > P_{t-2}, 0: \text{otherwise}\} \quad (2)$$
$$I_4 = \{1: \text{if } mmaP_{t-1} > mmaP_{t-2}, 0: \text{otherwise}\} \quad (3)$$
$$I_5 = \{1: \text{if } lmaP_{t-1} > lmaP_{t-2}, 0: \text{otherwise}\} \quad (4)$$
$$I_6 = \{1: \text{if } P_{t-1} > mmaP_{t-1}, 0: \text{otherwise}\} \quad (5)$$
$$I_7 = \{1: \text{if } P_{t-1} > lmaP_{t-1}, 0: \text{otherwise}\} \quad (6)$$
$$I_8 = \{1: \text{if } mmaP_{t-1} > lmaP_{t-1}, 0: \text{otherwise}\} \quad (7)$$
$$I_9 = \{1: \text{if } mmaP_{t-2} > lmaP_{t-2}, 0: \text{otherwise}\} \quad (8)$$
$$I_{10} = \{1: \text{if } V_{t-1} > V_{t-2}, 0: \text{otherwise}\} \quad (9)$$

Decision Making of Trading Agents

The agent trades for its speculation in the dynamic market. To make its order to the market, the agent forecasts the change of market price based on the information. Many agents possibly use the information for the prediction of market price behavior, and the information, especially the internal one, are formed as the emergence of such individual behavior. Therefore, the information become available ones for each agent, and must be the key to analyze the link between the micro and macro level behavior.

The decision making process of an agent, which is denoted as the agent k, consists of four steps, that is, translating the world information, forecasting the market price, making an order, and learning the prediction factor. In the translating step, the agent k observes the world information and translates it to the input signals for decision-making. In the forecasting step, the agent k forecasts the next time market price based on the input signals. In the making an order process, the agent decides the desirable quantity of kept risky stock, and makes an order to control the quantity of the stock based on the comparison with the actual quantity. And in the learning step, the agent modifies its prediction factor by the error between the predicted price and the achieved one in the market.

In detail, the agent k behaves according to the following steps.

Step 1: translate the external and internal information to the input signals.

Step 2: forecast the change value of market price based on the input signals.

Step 3: determine the desirable quantity of risky stock in the next time.

Step 4: choice either sell or buy order and decides the quantity of order according to the difference with the desirable quantity and actual one.

Step 5: modify the forecasted change value to the realized one.

Translation and Decision Making

To translate the information consisting of the external and internal one, the agent k maps the world information to the input signals. In this agent model, the agent k simply translates the intarnal information to the input signals as $i_j^k = I_j, 3 \le j \le 10$, but, the agent k translates the external information, that is, I_1, I_2, I_3, to the external signals i_1^k, i_2^k, i_3^k according to the following equations.

$$i_j^k = \begin{cases} I_j & \text{if } rand(0,1) < sync^k \\ RAND\{0,1\} & \text{otherwise} \end{cases} \quad (10)$$

where, the function $rand(a,b)$ returns the real value randomly selected from a to b, and $sync^k (0 \le sync^k \le 1)$ is the parameter of synchronization rate with the external signals. If this parameter is set close to 1, this agent synchronously maps the external information to the external signals. If this parameter is close to 0, this agent ignores the external information, and tries to utilize own personal information, that is, noise information.

In the viewpoint of macro behavior, if many agents synchronize to the external information with high values of $sync^k$, it is expected that the external information is common and available one for participant agents because macro behavior of agents is weakly linked through its information. On the other hands, if many agents asynchronously use the external information with small values of $sync^k$, the external information must not be common information and becomes unavailable one for other synchronizing agents. Therefore, we try to analysis the micro-macro structure of external information in various settings of these values.

After translation of the world information to the input signals $(i_0^k, i_1^k, \ldots, i_{10}^k)$, the agent k forecasts the next market price for making an order to the market. Let $a_t^k(i_0^k, i_1^k, \ldots, i_{10}^k)$ be a predicted change value of the market price in the condition of the input signals $(i_0^k, i_1^k, \ldots, i_{10}^k)$, the predicted change value of market price between $t-1$ and t is defined as follows.

$$y_t^k = a_t^k(i_0^k, i_1^k, \ldots, i_{10}^k) \tag{11}$$

According to the predicted change value, the agent k can easily decides the desiable quantity of risky stock as follows.

$$\hat{q}_t^k = round(y_t^k/\lambda^k) \tag{12}$$

where, the function $round(a)$ rounds the real value a to the nearest integer value. The parameter $\lambda^k (0 \leq \lambda)$ means the risk averse rate of agent k. If this value is small, the agent k tries to make a large profit with high risk. If this value is large, the agent tends to avoid the risk for losing its property, but this agent can not have chance to make a large profit.

Next, the agent k makes an order to the market in order to control the quantity of its risky stock to the desirable quantity $\hat{q}_t^k$. The order of agent k, o_t^k, is calculated as follows.

$$o_t^k = \hat{q}_t^k - q_t^k \tag{13}$$

If o_t^k takes negative value, the agent k makes a sell order, and the quantity of order is $-o_t^k$. Otherwise, the agent makes a buy order with the quantity o_t^k. The order price of agent k is simply decided as the predicted one, $P_{t-1} + y_t^k$. After all trading agents complete to make orders, these orders are gathered to the market, and the market contracts the combination of sell and buy orders in the equilibrium point that the quantities of supply and demand are evenly balanced. Then, the market price P_t is fixed, and this price effects the internal information.

Learning

In order to learn the change value of market price, a trading agent must modify the set of change values a_t^k by the result of market behavior. In the learning process, we adopt very simple learning method like that the predicted change value is modified according to the actual change value between P_{t-1} and P_t.

Let R_t be the reinforcement value, which is the actual change value between time $t-1$ and t, and it is represented as

$$R_t = P_{t-1} - P_t \tag{14}$$

The learning equation of change value defined as follows is applied to the agent k in each simulation time.

$$a_{t+1}^k(i_0^k, i_1^k, \ldots, i_{10}^k) = \gamma^k \cdot a_t^k(i_0^k, i_1^k, \ldots, i_{10}^k) + (1-\gamma^k) \cdot R_t \tag{15}$$

Table 1: Experimental Settings. In the table, $rand(a, b)$ is the function to return uniformly randomized real value from a to b. $nrnd(a, b)$ returns the randomized value based on the normal distribution with mean a and distribution b.

γ^k	$rand(0,1)$
$1/\lambda^k$	$rand(0,5)$
$a_0^k(i_0^k, i_1^k, \ldots, i_{10}^k)$	$nrand(0,10)$
$sync^k$ (setting 1)	0.0
$sync^k$ (setting 2)	0.5
$sync^k$ (setting 3)	1.0

Table 2: The time to converge in each experiment. The numbers of time are averaged in 15 trials in each experiment. Std. Dev. means the standard deviation of each trial. In addition, Exp. 1-1 indicates the experiment in setting 1, Exp. 1-2 is in setting 2, and Exp. 1-3 is in setting 3.

	Exp. 1-1	Exp. 1-2	Exp. 1-3
Averaged Time	707.7	834.1	955.6
(Std. Dev.)	(355.9)	(586.6)	(520.0)

where, the parameter γ^k is the learning rate of agent k. If γ^k is set to a small value, the agent k modifies its learned rate slowly. If γ^k is set to a large value, the agent k drastically modifies its learned rate according to the recent change of actual market price.

Experimental Results

Experiment 1

In the computer experiment, we prepared the parameter settings shown in Tab. 1. The parameters γ^k and $1/\lambda^k$ are set to independent random values in every agent. That is, the learning rate and risk averse rate are heterogeneous in every agent. The initial set of predict factor a_0^k is set with normal distribution random values. The setting of parameter $sync^k$ was prepared three types, i.e., setting 1, setting 2, and setting 3. In each setting, the value of $sync^k$ is set to same one in all agents. The setting 1 is supposed that the market with the information structure based on entirely same interpretation, the setting 3 is supposed that the market with entirely independent interpretation, and the setting 2 is intermediate of two settings. For the extension, it is able to prepare the set with variety $sync^k$ but we did not adopt it for investigation of basic behavior of proposed model. The main purpose of simulation is to investigate the effectiveness of information structure based on such basic settings.

For the first experiment, we focus the convergence of market behavior. In the proposed model, all trading agents learn with same reinforcement value simply, and it is expected that the behavior of market price would converge quickly. In such case, orders of traders converges to either sell or buy in the condition of information, and the equilibrium point of orders does not

Table 3: The average and standard deviation of the market price, and the balace shown in Figs. 2, ??, 3. The upper number and lower one in each cell represents the average and the standard deviation,respectively.

	Exp. 2-1	Exp. 2-2	Exp. 2-3
Averaged Price (Std. Dev.)	11416.78 (1147.03)	11129.80 (828.01)	10542.78 (312.46)
Averaged Volume (Std. Dev.)	536.85 (135.69)	547.68 (130.43)	570.3 (136.09)
Averaged Balance (Std. Dev.)	0.488 (0.085)	0.492 (0.079)	0.499 (0.078)

exist. Once the market behavior falls into such case, it can not escape from the convergence.

We prepared small group of 10 traders with the represented settings and the set of 15 trial simulations was carried out in each settings. Table 2 shows the time for achieving the convergence of market behavior in each setting. Table shows the averaged time for convergence in 15 trials and the standard deviation. In the results, the market of setting 1, which consists of traders with independent interpretation, converged earlier, and the market of setting 3, which consists of traders with common interpretation, converges later. This result is interesting that the time to converge in the setting 1 is shorter than 3 although the traders in 1 learn based on independent external signals each other, and the traders in 2 synchronously learn based on same external signals each other. In other words, the agent group of setting 1 treats heterogeneous interpretation, and the group of 3 treats homogeneous interpretation. Simply considering, it seems more difficult to learn in heterogeneous interpretation than in homogeneous interpretation.

The reason why the market in setting 1 converges earlier is considered as follows. In the market of setting 1, each trader uses the external signals with independent translation, and the external signals are unavailable because these can not be linked to the macro behavior and not be distinguished by the agent. Namely, the traders in setting 1 learn the prediction in only the conditions of internal signals, which pattern is 2^8. On the other hands, the traders in setting 3 make a decision based on the same external signals with common translation, and the behavior of market can be distinguished in the condition of internal signals. Then, the external information becomes to have the worth for the traders, and the traders learn the prediction in the conditions of the combination of external and internal signals, which pattern is 2^{11}. Therefore, the pattern for learning is less than in the setting 1, and such difference of information structure, which is able to be known from the viewpoint of macro-level, is considered to cause the difference of convergence between the settings.

Experiment 2

In the experiment 1, the behavior of market converges because all traders learn based on same reinforcement learning value and the members of system are fixed through the time, namely, the closed system. As the next experiment, we focus on the situation that the members of system are not fixed and changed, that is, the open system. In the open system, the learned decision-making of agents is changed according to the stream of members, and the investigation of forming process in such system is important to clarify the relationship between the information and interpretation in economic sense. In the experiment 2, the behavior of open system is investigated in the viewpoint of macro behavior and information structure.

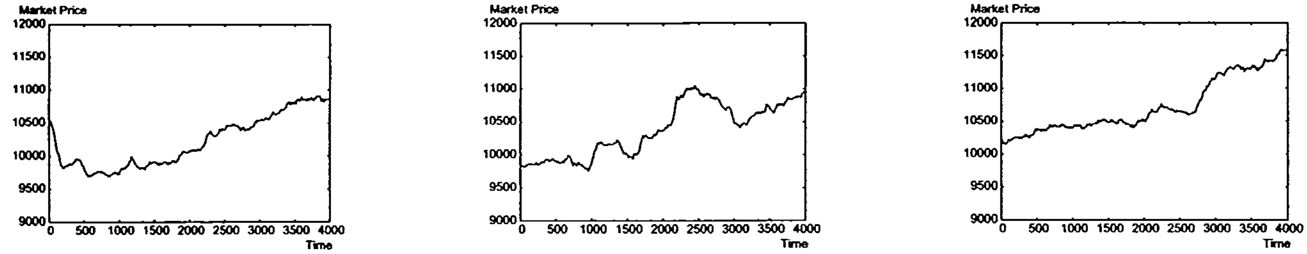
In the concrete, we prepared 50 traders for the experiment 2 with same settings in experiment 1, i.e., setting 1, 2, and 3. The different point compared with the experiment 1 is that each trader is initialized its parameters with the probability 3% in each time. It very simply extends the closed system to the open system like that some traders go and other ones come in each time. By the suppose of the open system, the behavior of market is considered not to converge.

We carried out 10 trials with 4000 simulation time in each settings. Fig. 2 shows the examples of time series data of market price in one trial of each setting. It is observed that the behavior of market price did not converge in each setting but is not observed the different aspects from these graphs.

Moreover, Fig. 3 shows the examples of time series data of the market balance, which represents the balance between the volume of sell and buy orders. The balance in each time is calculated to divide the volume of sell orders by the total volume of both sell and buy orders. If this value is close to 0 or 1, the balance of orders inclines to the one side. In each graph, the balance fluctuates around 0.5.

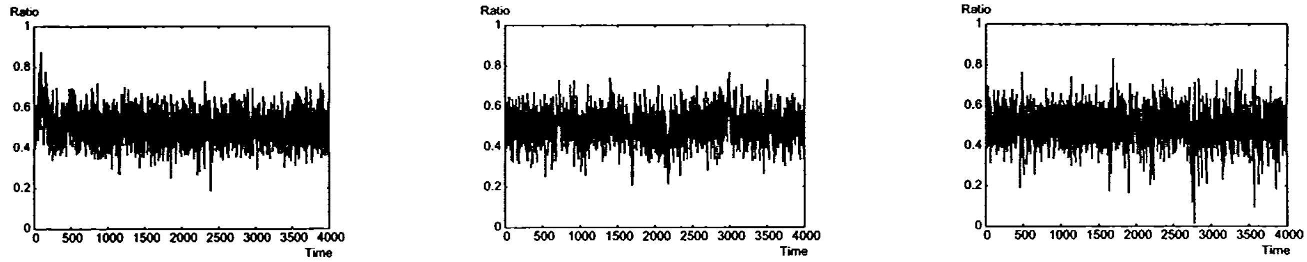
The average and standard deviation of 10 trials data in each settings is shown in Tab. 3. According to the results of Tab. 3, the change of market price (standard deviation of market price) in the setting 1 is larger than other settings, also the change of balance (standard deviation of balance) in the settings is larger. This phenomenon that the behavior of market in the setting is changeable compared with other settings is considered as based on same reason in the experiment 1. The independent interpretation makes the external information unavailable, and all traders become to regard only the internal information as important. Then, the unbalance of orders occurred according to the progress of learning, and the market price is changeable.

As the result of experiment 2, it is indicated that the situation that the traders have common interpretation of information leads the fertility of macro behavior and the dimension of macro level behavior is higher compared with the case of independent interpretation. It is difficult to model the relationship between the real market and real information, and the model used in this study is too simple to explain the real behavior of market. However, it is important result that this artificial market model with simple information structure causes the difference of macro-level behavior.



(a) Result of experiment 2-1. (b) Result of experiment 2-2. (c) Result of experiment 2-3.

Figure 2: Examples of time series data of market price. In each graph, X-axis indicates the number of simulation time, and Y-axis represents the market price of risky stock.



(a) Result of experiment 2-1. (b) Result of experiment 2-2. (c) Result of experiment 2-3.

Figure 3: Examples of time series data of the balance in sell and buy orders. In each graph, X-axis indicates the number of simulation time, and Y-axis represents the ratio of sell order volume in total volume of both orders. The ratio is simply calculated to divide the volume of sell orders by total volume of both sell and buy orders.

Conclusions

In this paper, we focus on the relationship between the information structure and the interpretation in artificial market. In the traditional economics theory like EMH, it is supposed that the universal interpretation of information exists in advance, and the importance for traders is whether it is known or not. However, in real world, it is often observed that the information which is essentially unrelated with the market affects the behavior of market. In one hypothesis, such phenomena can be understood that it is supposed the formation process of of interpretation between leaning trader. According to the results of simulation, we show the relationship between the information structure and macro behavior of market, although the model is very simple. On the other words, it is shown that simple model can lead the difference of market behavior.

References

[1] *The morning paper of Nihon Keizai Shinbun news paper.* Nihon Keizai Shinbun, 17, April, 2001 (in Japanese).

[2] *The morning paper of Nihon Keizai Shinbun news paper.* Nihon Keizai Shinbun, 16, May, 2001 (in Japanese).

[3] K. Izumi. Complexity of agents and complexity of markets. In *International Workshop on Agent-based Approaches in Economic and Social Complex Systems (AESCS2001)*, pages 43–50, 2001.

[4] W. Arthur. Designing economic agents that act like human agents: A behavioral approach to bounded rationality. *the American Economic Review*, 81(2):353–359, 1991.

[5] W. Arthur, J. Holland, B. LeBaron, R. Parmer, and P. Tayler. Asset pricing under endogenous expectations in an artificial stock market. *The Economy as an Evolving Complex Systems*, 2:15–44, 1997.

[6] B. Edmonds. The use of models - making MABS more informative. In *Multi-Agent-Based Simulation, LNAI 1979*, pages 15–32. Springer, 2000.

[7] S. Moss. Editorial introduction: Messy systems - the target for multi agent based simulation. In *Multi-Agent-Based Simulation, LNAI 1979*, pages 1–14. Springer, 2000.

[8] R. Parmer, W. Arthur, J. Holland, and B. LeBaron. An artificial stock market. *Artificial Life Robotics*, 3:27–31, 1999.

[9] H. Kawamura, A. Ohuchi, and K. Kurumatani. Development of X-Economy system for introduction of artificial market. In *International Workshop on Agent-based Approaches in Economic and Social Complex Systems (AESCS2001)*, pages 51–58, 2001.