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AGENT-BASED SIMULATION AND GREENHOUSE GAS EMISSIONS TRADING

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ABSTRACT

The need for new theoretical and experimental approaches to understand dynamic and heterogeneous behavior in complex economic and social systems is increasing recently. An approach using the agent-based simulation and the artificial market on the computer system is considered to be an effective approach. The computational simulation with dynamically interacting heterogeneous agents is expected to re-produce complex phenomena in economics, and helps us to experiment various controlling methods, to evaluate systematic designs, and to extract the fundamental elements which produce the interesting phenomena for future analytical works. In the previous works, we investigated the stability of a virtual commodities market and the aggregated behavior of the dynamic online auctions with heterogeneous agents. In this paper, we will introduce a simple framework to develop agent-based simulations systematically and consider an application of the agent-based simulation for a dynamical model of the international greenhouse gas emissions trading.

1 INTRODUCTION

In real economic situations, the dynamic behavior and interactions between people are very complicated and may often seem irrational. Further complicating the situation, the recent progress and popularity of network communication technologies greatly widens the diversity of participants and affects the market mechanism itself, and increases the dynamic fluctuations of economic systems.

In the past, traditional economic theories have only considered idealized representative participants in equilibrium states. It is very difficult to analyze dynamically changing situations involving heterogeneous subjects using such static and homogeneous methods.

In the last decade, many researchers, including physicists and computer scientists, are starting to apply new approaches to investigate such complex dynamics in the their studies of economics. One of these approaches is the agent-based simulation approach.

The term "agent" is often used with different meanings by different researchers. For example, the word agent may refer to an autonomous graphical user interface with animation, a robot who gathers information from a network, an artificial lifeform, or a distributed application which collaborates with other components over the network. In the study of economics, an agent usually means an independent economic entity like a household or a firm. But usually, traditional economic theories consider only representative agents in equilibrium states. By using simulation technology, we can endow such economic agents with heterogeneous and dynamic properties. Thus, when we refer to an agent-based simulation, we assume a simulation study of an economic system composed of heterogeneous and dynamic economic entities

Large-scale agent-based simulations have become possible only relatively recently, with the advent of fast, cheap, and readily available computers. The approach has been championed by physicists using the paradigm of computational statistical physics. de Oliveira, de Oliveira, and Stauffer (1999) review several papers from the past few years that exemplify the methodology, especially the work of Levy, Levy, and Solomon (1994). This opens the door to the study of the interaction of large numbers of heterogeneous, interacting agents.

In this paper, we will introduce a simple framework for agent-based simulation and three applications: a market simulation, a dynamic online auction, and international greenhouse gas emissions trading.

2 AGENT-BASED SIMULATION FRAMEWORK: ASIA

For effective implementations of the agent-based economic and social simulations, we developed a simple framework, Artificial Society with Interacting Agents (ASIA), with Java.

This framework provides only very simple and fundamental functionality for the social simulation.

Recently, a lot of researcher comes to investigate agent-based simulations or artificial markets. Also a number of agent system or framework are proposed to implement models systematically. Many of other frameworks aim at constructing unified structures with object-oriented design methods (For example, Iba et al. 2000) and some of them also possess an intelligent collaboration mechanism through the network.

On the other hand, our framework mainly determines dynamic interactions and trading process as foundations, and leaves concrete design of agent's hierarchy, social structure and individual strategy for users. We consider that this difference mainly comes from the difference of the concept of agent as described in the introduction.

We constructed the framework with layer structure as shown in Figure 1. The agent layer contains a basic agent class and the fundamental environment for the agents. The environment provide the fundamental facilities for agents and users to create agents, to dispose agents, and to send messages through a MessageManager class.

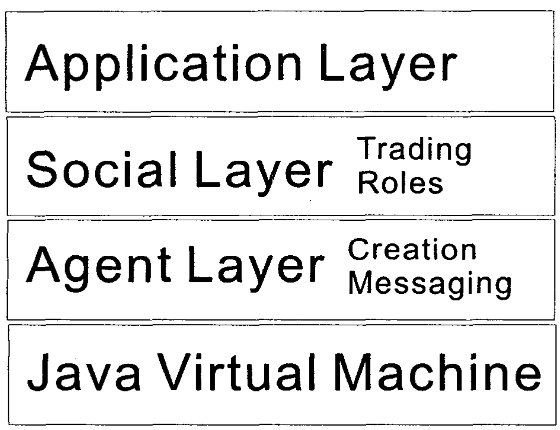

Figure 1: Layer Structure in ASIA

The MessageManager gathers and distributes messages sequentially with his own thread according to the predetermined schedule. Agents also have their threads to process the distributed messages. Thus, users of the upper layers can construct parallel communication among agents without bothering about message passing mechanism.

The social layer describes the basic role of agents in the society and gives the example of message exchanges for trade. We implemented Central, Participant, and Watcher agents and simple market process using RFB and BID messages. The Central agent creates, registers and initiates Participant agents and Watcher agents. Users can start, stop, and reset trading through the GUI window provided by the Central agent.

One trade procedure is executed as follows (see Figure 2). To begin a trade, the Central agent send Request For Bid (RFB) message to each Participant. Upon receiving a RFB message, a Participant agent reply with a BID message. Then, the Central agent aggregate all BID messages and proceed to the trade transaction if users customize the descendant appropriately. Finally, each Watcher agent receive information of the trade and report it to users in the desired format.

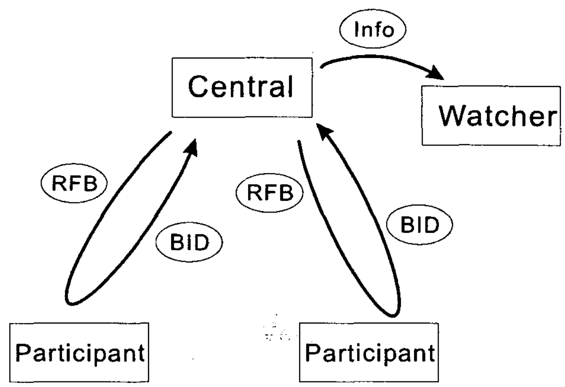

Figure 2: Message Transactions in the Social Layer

The social layer only determine a formal procedure of trading and users must customize the behavior of agents at the Application layer.

In the following sections, we will give applications of this framework.

3 MARKET SIMULATION

The stability of prices in asset markets is clearly a central issue in economics. From a systems point of view markets inevitably entail the feedback of information in the form of price signals, and like all feedback systems may exhibit unstable behavior.

Steiglitz and Shapiro (1998) created the price oscillation and bubbles in a simple commodity market with producer/consumer agents and two types of speculators. Mizuta, Steiglitz, and Lirov (1999) considered the stability in this model with various price signals and found that the anti-weighted average of bid price stabilizes the market dramatically.

In this section, we re-produce the simulation model described in Mizuta, Steiglitz, and Lirov (1999) with the ASIA framework.

We use two commodities: *food* and *gold*.

As an descendant of Central agent, we consider a central auctioneer. There are three Participant agents. Regular agents produce food or gold and consume food; value traders and trend traders are solely speculators.

One trading period is executed as follows. The auctioneer sends to each agent a Request For Bid (RFB) containing price signals. Consider first the case when the price signal is simply the previous closing price, as in Steiglitz and Shapiro (1998) and Steiglitz, Honig, and Cohen (1996). Based on this signal, the regular agents decide on their levels of production for that time step, speculators update their estimates. The agents then send bids to sell or buy. Finally, the market treats the submitted bids as a sealed-bid double auction and determines a single price which maximizes the total amount of food to be exchanged.

In each trading period the regular agents can produce either food or gold. They make this production decision to maximize profit, but in a shortsighted way, based only on the current price and their production skills.

Figure 3 shows the screen shot of the system. PriceAmount Watcher indicates two graphs showing the market clearing price and the traded amount.

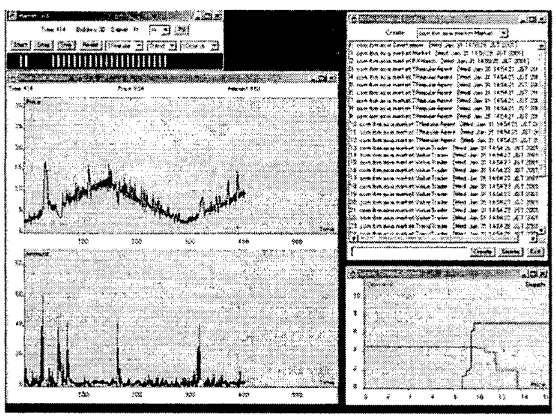

Figure 3: Market Simulation with Agent Framework ASIA, Showing a Price Bubble

In the previous works we showed that the price oscillation with Regular agents is stabilized by introducing different price signals. On the basis of the simulation, we also gave analytical results on the simplified dynamical system with different signals in Mizuta, Steiglitz, and Lirov (1999).

4 DYNAMIC ONLINE AUCTIONS

The use of online auctions is rising at a dramatic rate, and in general many segments of the economy are becoming granulated at a finer and finer scale. Thus, understanding behavior in auctions, and especially the interaction between the design of auctions, agent behavior, and the resulting allocations of goods and money has become increasingly important—first because we may want to design auctions that are as profitable as possible from the sellers' point of view, but also because we may want to bid in auctions, or design computer systems that respond well to the loads that auctions generate. To investigate such a dynamical interaction between heterogeneous bidders and the price formulation through successive auctions, Mizuta and Steiglitz (2000) developed an agent-based simulation of the dynamic online auctions (see Figure 4).

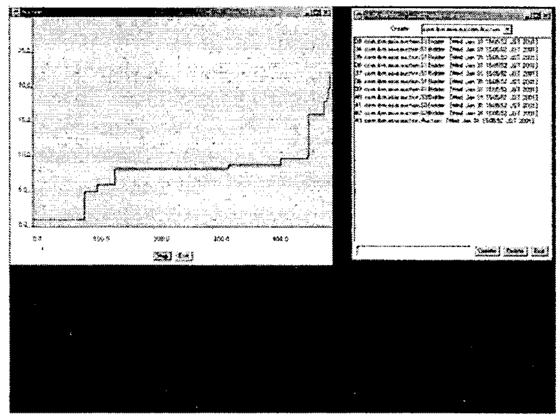

Figure 4: Auction Simulation with Agent Framework ASIA

In this model, there are two different types of bidders; *early bidders*, who can bid any time during the auction period, update his valuation continuously and compete strongly with each other, and *snipers*, who wait till the last moments to bid. We can briefly characterize the strategy of early bidders as watch/modify/bid, and that of snipers as wait/bid.

The simulated bidding history shows complicated and realistic behavior with the collaboration of these heterogeneous agents.

5 GREENHOUSE GAS EMISSIONS TRADING

In this section, we consider the application of the agent-based simulation for the international greenhouse gas (GHG) emissions trading under the Kyoto Protocol (KP).

To prevent the global warming, 160 countries agreed to the KP on limiting GHG emissions at COP3 in 1997. KP sets targets for Annex I countries at assigned reductions below the 1990 levels, with the targets to be met during the commitment period 2008-2012. For example, Japan and the US should reduce 6% and 8% of their emissions, respectively. The KP allows international GHG emission trading, where countries who cannot reach the reduction targets can buy the emissions rights from other countries who can easily satisfy the target. Such a market mechanism is expected to reduce the worldwide cost for GHG reduction because of the large range in the marginal abatement cost curves (MACs) for reducing GHG emissions.

In the previous two sections, we have applied the simulation to relatively traditional market systems, that is, the commodities market and the online auction. Now we will investigate the anticipated properties of an emerging new market through a simulation study. Such a study in advance is important to establish efficient rules, but difficult without simulation.

Grütter (2000) developed the CERT model which calculate the equilibrium price with various options and parameters for MACs. The CERT model treats only one trade in 2010 and each country must achieve the targets in that year. Because this model is implemented with a spreadsheet and macros, it is difficult to expand the model to treat successive trades and to assign different strategies to different countries.

Now we have developed a prototype for GHG emissions trading with the ASIA framework. Because we constructed countries as agents, we can easily modify the behavior of each country and investigate the dynamic interactions between heterogeneous strategies.

The structure of the simulation system is as follows. A COP agent is a descendant of the Central agent and manages the international trading. Nation agents are descendants of the Participant agent and correspond to countries or groups. In this model, we create 12 Nations; 6 are Annex I countries and 6 are Non Annex I countries who are not assigned targets for reduction. Nations behave autonomously and independently to achieve KP targets assigned with minimum costs or to receive maximum profits from the trades.

Figure 5 shows the basic trading procedure through message exchanges. We consider both a static equilibrium market with only one trade in 2010, as was discussed in Grütter (2000), and dynamic market development through the commitment period 2008-2012. In each trading year, a COP agent sends Request for Bid (RFB) messages to all Nations which have an asking price. Upon receiving the RFB message, a Nation agent examine the asking price and his MAC to decide the amount of the domestic reduction. Then he sends back a Bid message to the COP agent which says how much he wants to buy or to sell at the asked price. After repeating this RFB-BID process, the COP model will find the equilibrium price where the demand and the supply balance, and send the Trade message to approve the trades for the year. Thus, the equilibrium price at one year is determined when the MAC functions and the assigned reduction of all participants are given.

Figure 6 shows a screen shot of the system. Users can start, stop, and reset the trades and select the trading duration in the main GUI window provided by the COP agent. This main window provides information for each Nation's agents, and buttons to open a GUI window for each Nation.

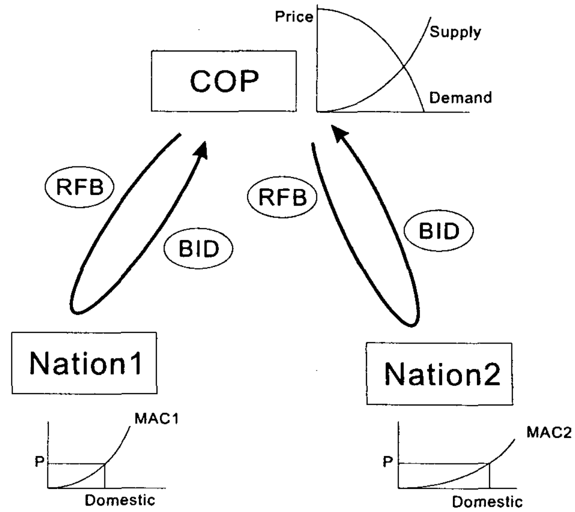

Figure 5: Trading Procedure

Users can also create a IPriceWatcher agent whose GUI window shows the graphs for price movements and the balance between demand and supply through the iteration of RFB-BID transactions. We can see that the price in the upper graph approaches to the equilibrium as the excess demand in the lower graph shrinks.

Then, we consider the multiple trading periods. Nation i divide the assigned reduction R_i into each year $n = 0, 1, 2, \ldots$,

$$\sum_n R_{in} = R_i.$$

As described previously, we can find the equilibrium price P_n^* at each year using a partition of the assigned reduction R_{in} and a MAC function at the moment. To consider the dynamics of MAC, we introduce a technology function $t_{in}(p)$ which gives the amount of reduction using the available technology at a given cost p for the Nation i at the year n. MAC is given as the inverse function of the integral of the technology function.

$$\text{MAC(amount)} \equiv D_{in}^{-1}(P),$$

$$D_{in}(P) \equiv \int_0^P t_{in}(p)dp,$$

where $D_{in}(P)$ is the cumulated amount of the domestic reduction using technologies which is cheaper than the given price P. The difference between the assigned reduction R_{in} and the domestic reduction $D_{in}(P)$ will be traded among

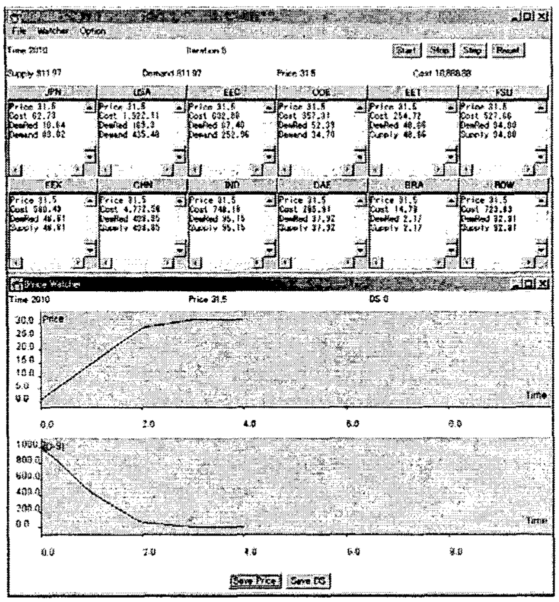

Figure 6: The Equilibrium Price for the GHG Emissions Trading

counties,

$$T_{in}(P) \equiv R_{in} - D_{in}(P).$$

At the equilibrium price P_n^*, there is no excess demand,

$$\sum_j T_{jn}(P_n^*) = 0.$$

This condition gives the equilibrium price using the assigned reductions at each year. Hence we can consider that the equilibrium price P_n^*, the domestic reduction at equilibrium D_{in}^*, and the trading amount at equilibrium T_{in}^* as functions of the assigned reduction R_{in}. The reduction cost at one year is given by

$$\tilde{C}_n(R_{in}) \equiv C_{in}(D_{in}^*(R_{in})) + T_{in}^*(R_{in})P_{in}^*(R_{in}),$$

where $C_{in}(x)$ is a domestic cost function defined by the integral of MAC.

At each year, all countries determine the amount of the domestic reduction with which the values of MAC for all countries agree with one international value, that is, the equilibrium price, to minimize the worldwide reduction cost. Similarly, the total cost over the commitment period will be minimized by choosing the partition R_{in} $(n = 0, 1, 2, \ldots)$ of the assigned reduction so that the differential coefficient of the total cost $\tilde{C}'_{in}(R_{in}) = P_n^* + T_{in}^*/\tau_n^*$ becomes constant over $n = 0, 1, 2, \ldots$, with $\tau_n^* \equiv \sum_j t_{jn}(P_n^*)$.

As a simple dynamic process for the reduction technology $t_{in}(p)$, we adopt reusability $0 \le \alpha \le 1$ and deflation $0 \le \gamma \equiv 1/\beta \le 1$. Once the technology whose cost is lower than the price P^* is used, the reusability of the technology will be restricted with the coefficient α. On the other hand, the technical innovations and deflation decreases the cost of the technology. With $\bar{P}_{in} \equiv \max\{\gamma_i^n P_0^*, \gamma_i^{n-1} P_1^*, \ldots, \gamma_i P_{n-1}^*\}$, we can obtain the technology function as

$$t_{in}(p) \equiv \begin{cases} \alpha_i \beta_i^n t_{i0}(\beta_i^n p) & p < \bar{P}_{in} \\ \beta_i^n t_{i0}(\beta_i^n p) & \text{otherwise.} \end{cases}$$

We assume the initial technology function $t_{i0}(p)$ with two coefficients a_i and b_i to reproduce the quadratic MAC function in the CERT model,

$$t_{i0}(p) \equiv \frac{1}{\sqrt{b_i^2 + 4a_i p}}.$$

In the simulation, we fix the parameters $\{a_i\}$, $\{b_i\}$ and $\{R_i\}$ for 12 countries as given in the CERT model and use randomly distributed $\{\alpha_i\}$ and $\{\beta_i\}$. Each Nation agent i determine the initial partition of the reduction $\{R_{in}\}$ and update them after the commitment period so that the variance of the marginal reduction cost $\{\tilde{C}'_{in}(R_{in})\}$ decreases.

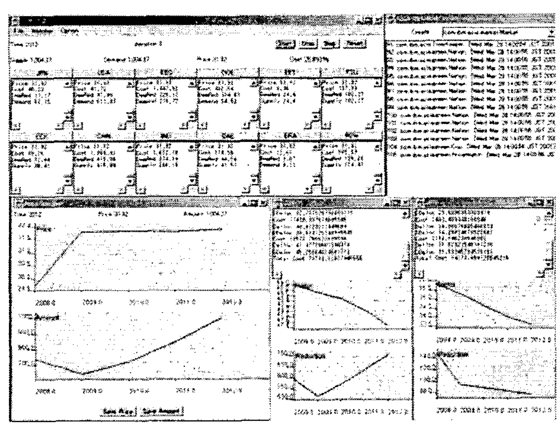

Figure 7: Dynamic GHG Emissions Trading over the Commitment Period, 2008–2012

Figure 7 shows an example of the simulation result. Two graphs in the lower left window show the movement of the equilibrium price and the trading amount. There are also graphs for the marginal reduction cost (upper) and the partition of the assigned reduction (lower) of two Nations representing USA (left) and Japan (right). By simulating the dynamical adjustment of the partition, we can see the worldwide cost reduction and the spontaneous selection of strategies. In this result, USA chose the late action and Japan chose the early action according to their estimation of the technical innovation and other circumstances.

6 CONCLUDING REMARKS

In this paper, we have described an agent-based simulation framework, ASIA, and its new application to international GHG emissions trading. To make it easy to implement various systems within this framework, we kept it simple, concentrating on parallel messages transactions between simple agents at the agent layer, and provided a sample trading pattern at the social layer.

At this stage of development, we did not provide intelligence or the network functions for agents which most other frameworks require, because our fundamental concept of an agent does not necessarily require these facilities. However, we do think that a wide range of agent-based simulations can be constructed within this framework. However, we also consider it will be useful for some users if some of these options are available in the higher layer as components they can choose. So, those optional components for our framework remain for future work. Furthermore, much of the research and analysis required to evaluate GHG emissions trading are also left for the future. We believe that this preliminary work will help in the effective construction of the emerging international market and that such an agent-based approach will have more importance in the near future.

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