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A multiagent-based complex systems approach for dynamic negotiation mechanism in virtual enterprise

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Abstract

Nowadays a sophisticated match-making mechanism is necessary for appropriate collaborations in virtual enterprise (VE). Virtual market based match-making operation enables effective partner search in terms of products allocation by distributing the scheduled resources according to the market prices, which define common scale of value across the various products. We formulate the VE match-making model as discrete resource allocation problem, and propose a complex market-oriented programming framework based on the economics of complex systems. Three types of heterogeneous agents are defined in the complex virtual market. It is described that their interactions with micro behaviour emerge a macro order of the virtual market, and the clearing price dynamism can be analysed in economic terms. The applicability of the framework into resource allocation problem for VE is also discussed.

Keywords: Multiagent systems; Complex systems; Partnering; Virtual enterprise

1. Introduction

In recent years consumers' demands have turned to be diversified, and enterprises must produce appropriate quantity of goods with reasonable price considering consumers' needs, such as fashions, quality, lead time, and so on. The introduction of information and telecommunication technologies and more recently, distributed object computing technology has enabled the creation of functioning virtual enterprises (VE) that do not have the geographic and structural restrictions that have traditionally constrained conventional enterprises. These technologies have enabled people to interact and collaborate effectively over distance as part of VE [1].

Traditionally, marketing, distribution, planning, manufacturing, and the purchasing organisations operated independently. These organisations have their own objectives and these are often conflicting. The result of these factors is that there is not a single, integrated plan for the organisation—there were as many plans as businesses. Clearly, there is a need for a mechanism through which these different functions can be integrated together. Although cooperation is the fundamental characteristic of VE concept, due to its distributed environment and the autonomous and heterogeneous nature of the VE members, cooperation can only be succeed if a proper management of dependencies between activities is in place just like Supply Chain Management [2,3].

On the other hand, market price systems constitute a well-understood class of mechanisms that provide effective decentralisation of decision making with minimal communication overhead [4]. In a market-oriented programming approach to distributed problem solving, the optimal resource allocation for a set of computational agents is derived by computing general equilibrium of an artificial economy [5,6]. Market mechanism can provide several advantages in the partnering process in VE. So as to facilitate the optimised VE management with e-commerce infrastructure, a sophisticated business matching mechanism is required to manage such a large-scaled environment. Since the match-making place is a kind of pure market in terms of its structure, the idea of VE combined with virtual market (VM) must be promising [3,7].

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In e-commerce, the diversification of consumers' needs makes it difficult for traders to make appropriate decision makings. So, in this study, we focus on subjects about how prices of the goods are decided and how the goods are dealt in among the enterprises that compose VE. Then we try to construct a VM based on the model of 'economics of complex systems' [8]. Economics of complex systems has several features: increasing returns to scale, bounded rationality, self-organisation, one-to-one trading, and so on.

2. Economics of complex systems

2.1. Economic systems

Economic systems are made of a large number of interacting agents and display also surprising self-organising features and macroscopic order in spite of the underlying disorder among its constituents. It is easy to understand why there is a great temptation to extrapolate that line of thought to account for some basic, stylised facts of economic systems. This approach, however, amounts to take especially into account the interactions among the agents, and the way in which they coadapt to each other and to regard equilibrium in a more dynamical way [8].

Last but not least economic systems drastically depart from other natural systems in their self-referential nature: the ones who predict the future course of the evolution of the system are a part of the same system being predicted. As in self a fulfilling prophecy, the evolution depends upon the perception that most actors have of the same evolution. This in turn depends upon the information that all economic agents have about the system as a whole. However, even in the case in which all the agents of the system would act as if they have extracted all the information available, the future would hardly be accurately anticipated.

In order to cope with these difficulties, economics is presently being enriched with a number of new concepts. The classical approach that puts emphasis in the idea of economic equilibrium dating from Walras in the past century [9] is being complemented with a viewpoint that focuses on the idea of change and evolution. Perfectly rational agents are being replaced by others with bounded rationality, imperfect information, behaving inductively on the grounds of reasonably formed expectations and capable of learning from adaptation. The search of optimality that in many circumstances requires that the economic agents should be endowed with the unrealistic capacity of solving NP hard or ill-defined problems is replaced by the search of robust suboptimal behaviours.

The general equilibrium models usually restrict themselves to consider only the final state of systems with stabilising negative feedbacks. Present day research is starting to put under close scrutiny the effects of relaxing this condition including non-convexities. Situations as these in which it is allowed an increasing return on the margin are for instance in the effects of scale production or in the development of markets for new technologies. Such interactions have a number of parallels in non-linear physical systems that have multiple ground states, or presenting lock-in or self-reinforcing processes in their evolution.

2.2. Concept on economics of complex systems

In coincidence with these new viewpoints new approaches are being seriously considered to construct working models of economic systems.

One of the most important approach is to combine economics and complex systems approach, named economics of complex systems. Within this framework it is possible to construct an economic system starting, bottom-up, by its most elementary ingredients. An economic system is visualised as a large number of interacting agents whose individual actions as well as the interactions among them are explicit enough to be put into algorithmic terms. Although this approach bears the advantage of imposing weaker restrictions than a purely mathematical one, it is still necessary to greatly simplify the real situations. The challenge is that the essential features that are responsible for the emergent behaviours of the system do not get lost. A successful model, in spite of being a heavy abstraction of real economic systems, allows discussing basic, stylised facts and working as true laboratories in which extreme conditions can easily be simulated and studied.

The main motivation of the economics of complex systems is to study the self-organising driving forces that act within an economic system. The hope is that learning about them can also provide information about the mechanisms that drive economic systems towards or away a stationary situation. The search of a global stable configuration and the process of self-organisation are the two main emergent properties to clear about. A particularly relevant ingredient to model the relaxation of an economic system off equilibrium is both, the expectations and the adaptive capacity of its economic agents. Most of the robustness of the system as a whole can certainly be attributed to the memory that agents have of their previous experiences in deciding their future attitudes in their economic transactions. Adaptation on the other hand provides the necessary plasticity and change of individual behaviours to absorb changes and shocks. Learning and adaptation may therefore be considered as the basic element to model the self-organising features of an economic system, as well as its robustness—or equivalently—its bounded homeostasis.

We formulate VE model as discrete resource allocation problem based on negotiated transaction, and propose a complex VM framework based on the economics of complex systems in this paper.

3. Agent formulation

3.1. VM structure with complex systems

VM consists of three types of agents in this study, such as producer agent, customer agent, and intermediate agent, because the VM provides auction environment for enterprises in VE.

- Producer agent: Players who produce and supply exchanging resources in VM.
- Customer agent: Players who buy and consume the resources in VM.
- Intermediate agent: Players who provide auction field, and intermediate the trades between producer and customer agents. As a consequence, individual match makings are established between a set of producer and customer agents. As a basic study, the intermediate agents are assumed never to try to gain profit during the matching process, and just offer the match-making opportunity in this study.

Negotiations are occurred just between producer agent and intermediate agent, or customer agent and intermediate agent in this study. Thus all the tradings in the VM are based on negotiated transaction, which is completely different from the intensive transaction in stock exchange market, i.e. Walras market proposed in micro economics.

In the proposed VM structure with complex systems, market environment is divided into finite number of small grids where only one agent is located inside. Initially all the agents are located randomly, and they are assumed not to move their locations as a basic study. Both the producer agent and the customer agent behave individually without any contact to other agents except the intermediate agent. Only the intermediate agent has a transactional scope, and the intermediate agent is able to make communications or negotiations with other agents inside the scope. The negotiation is carried out in one to one relationship between producer agent and intermediate agent, or customer agent and intermediate agent as negotiated transactions. The scope corresponds to information transmission space, i.e. information distance, in practical situations.

3.2. Producer (i.e. supplier) agent (s)

Producer agent tries to pursue its profit by producing and selling goods x from its own capital. We formulate the producer agent (s) as follows:

(a) *Objectives*: Maximise its capital (M_s^t) at present (t)

$$M_s^t \to \max. \tag{1}$$

(b) *Behaviour*:

Step 1: Produce goods x by the amount (O_{sx}^t) that calculated previous Step 5, and increase its stock (G_{sx}^t):

$$G_{sx}^t = G_{sx}^{t-1} + O_{sx}^t. \tag{2}$$

Step 2: If the estimated profit ($EPro_{sx}^t$) is not negative, decide to sell all the stock and go to Step 3 (Case 1). Otherwise give up to sell and go to Step 4 (Case 2):

$$EPro_{sx}^t = P_{sx}^t - C_{O_s x}, \tag{3}$$

where P_{sx}^t is the recommended price, $C_{O_s x}$ the cost price.

Step 3: Carry out transactions with the intermediate agent, and modify its capital (M_s^t) according to the transactions. The details are described in Section 3.4:

$$SL_{sx}^t = \sum_d \{(MP_{sxd}^t - C_{O_s x}) * n_{sxd}^t\}, \tag{4}$$

$$M_s^{t+1} = M_s^t + \sum_x SL_{sx}^t, \tag{5}$$

$$G_{sx}^{t+1} = G_{sx}^t - \sum_d n_{sxd}^t, \tag{6}$$

where SL_{sx}^t is the total sales, MP_{sxd}^t the clearing price, n_{sxd}^t the amount of trade.

Step 4: Calculate the recommended price (P_{sx}^{t+1}) for the next step ($t+1$):

$$P_{sx}^{t+1} = \begin{cases} P_{sx}^t * \alpha_{sx} & \text{Case 1}, \\ P_{sx}^t + \pi & \text{Case 2}, \end{cases} \tag{7}$$

where α_{sx} is the price modify parameter, π the price increase parameter.

Producer agent modifies parameter α_{sx} according to the amount of trade. If the total amount of trade is equivalent to the prepared stock, the agent increases the price for expecting higher profit at the next step. On the contrary, if it has no offer from intermediate agent, it decreases the price as follows:

$$\alpha_{sx} = \begin{cases} u_+ & \left(\sum_d n_{sxd}^t = H_{sx}^t\right), \\ u_0 & \left(0 < \sum_d n_{sxd}^t < H_{sx}^t\right), \\ u_- & \left(\sum_d n_{sxd}^t = 0\right), \end{cases} \tag{8}$$

where $\sum_d n_{sxd}^t$ is the total trading amount, H_{sx}^t the desired sales amount, $u_0 = 1.0$, $u_+ > 1.0$, and $u_- < 1.0$.

Step 5: Calculate the production amount so as to maximise its profit by solving NLP problem $\mathfrak{R}$ as follows:

Problem $\mathfrak{R}$:

$$\text{Maximise} \quad \Pi = P_{sx}^{t+1} O_{sx}^{t+1} - (C_{O_s x} R_{sx}^{t+1} + C_s) \tag{9}$$

$$\text{Subject to} \quad O_{sx}^{t+1} \leqslant f(R_{sx}^{t+1}), \tag{10}$$

where $C_{O_s x}$ is the material prise, R_{sx}^{t+1} the material amount, C_s the fixed cost.

The parameter Π means profit, and f is the production function. Producer agent is formulated to maximise its profit locally by solving the above NLP.

Production function: Production function is defined as the combination of increasing return and diminishing return shape, which is observed commonly in practical industry [10], and finally we can obtain Eq. (11) from Eq. (10):

$$\text{Subject to}\quad l(O_{sx}^{t+1}-a)^3+m(O_{sx}^{t+1}-a)^2 + n(O_{sx}^{t+1}-a)=R_{sx}^{t+1}-b, \tag{11}$$

where l, m, n, a, b is the constant values.

An example of the proposed production function is shown in Fig. 1.

(c) *Withdrawal conditions*: If the agent exhausts its capital, then it withdraw from the market.

3.3. Consumer (i.e. demander) agent (d)

Consumer agent is assumed to try to purchase goods x and sell it to the market underneath in supply chain. The underneath market is not modelled precisely in this study and it is assumed as fully stable as a basic research. We formulate the consumer agent (d) as follows:

(a) *Objectives*: Maximise its capital (M_d^t) and stock (G_{dx}^t) at present (t)

$$M_d^t \to \max \wedge G_{dx}^t \to \max. \tag{12}$$

(b) *Behaviour*:

Step 1: Increase capital (M_d^t) with sales income (C_{Md}):

$$M_d^t = M_d^{t-1} + C_{Md}. \tag{13}$$

Step 2: Carry out transactions with the intermediate agent, and modify its capital M_d^t. The details are described in Section 3.4:

$$PY_{dx}^t = \sum_s MP_{dxs}^t * n_{dxs}^t, \tag{14}$$

$$G_{dx}^{t+1} = G_{dx}^t + \sum_s n_{dxs}^t, \tag{15}$$

$$M_d^{t+1} = M_d^t - \sum_x PY_{dx}^t, \tag{16}$$

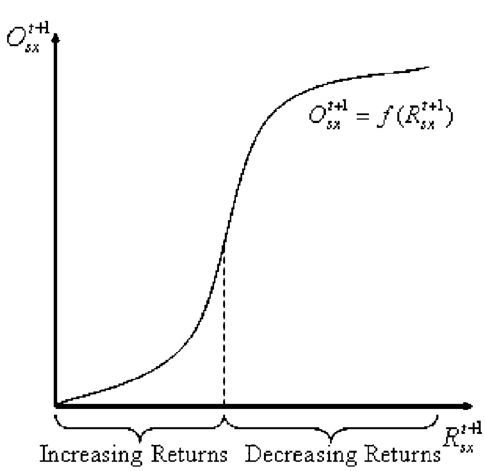

Fig. 1. Production function.

where $\sum_x PY_{dx}^t$ is the total cost, $\sum_s n_{dxs}^t$ the amount of purchased goods.

Step 3: Calculate the desired purchase price (P_{dx}^{t+1}) for the next step ($t+1$):

$$P_{dx}^{t+1} = P_{dx}^t * \alpha_{dx}. \tag{17}$$

Consumer agent modifies parameter α_{dx} according to the amount of trade. If the total amount of trade is equivalent to its requirements, the agent decreases the price for lower expenditure. On the contrary, if it has no offer from intermediate agent, it increases the buying price:

$$\alpha_{dx} = \begin{cases} u_+ & \left(\sum_s n_{dxs}^t = 0\right), \\ u_0 & \left(0 < \sum_s n_{dxs}^t < H_{dx}^t\right), \\ u_- & \left(\sum_s n_{dxs}^t = H_{dx}^t\right), \end{cases} \tag{18}$$

where H_{dx}^t is the required amount.

Step 4: Calculate the requiring amount in the next step (H_{dx}^{t+1}) by solving the following simultaneous equations:

$$M_d^{t+1} = \sum_x P_{dx}^{t+1} H_{dx}^{t+1}, \tag{19}$$

$$\frac{P_{dx_1}^{t+1} H_{dx_1}^{t+1}}{P_{dx_2}^{t+1} H_{dx_2}^{t+1}} = \mathrm{MRS}_{x_1 x_2}^{t+1}. \tag{20}$$

MRS means marginal rate of substitute, and MRS between goods x_1 and x_2 are formulated as follows:

$$\begin{aligned} \mathrm{MRS}_{x_1x_2}^t &= \frac{\mathrm{d}G_{dx_2}^t}{\mathrm{d}G_{dx_1}^t} = \frac{\partial W_d^t/\partial G_{dx_1}^t}{\partial W_d^t/\partial G_{dx_2}^t} \\ &= \frac{\lambda_{dx_1} G_{dx_1}^{t\ (\lambda_{dx_1}-1)} G_{dx_2}^{t\ \lambda_{dx_2}}}{\lambda_{dx_2} G_{dx_1}^{t\ \lambda_{dx_1}} G_{dx_2}^{t\ (\lambda_{dx_2}-1)}} \\ &= \frac{\mu_{dx_1} G_{dx_2}^t}{\mu_{dx_2} G_{dx_1}^t} = \frac{G_{dx_2}^t/\mu_{dx_2}}{G_{dx_1}^t/\mu_{dx_1}} = \frac{\tau_{dx_2}}{\tau_{dx_1}}. \end{aligned} \tag{21}$$

W_d^t is the welfare function, which represents the utility of agent d with current stocks, and it is generally described as [11]

$$W_d^t = \prod_x G_{dx}^{t\ \lambda_{dx}} \quad \left(\text{s.t.} \sum_x \lambda_{dx} = 1\right), \tag{22}$$

where $\lambda_{dx} = \mu_{dx}/\sum_x \mu_{dx} > 0$ and μ_{dx} means consumption rate of x at one step.

τ_{dx} represents the time period to be exhausted of goods x in agent d:

$$\tau_{dx} = \frac{G_{dx}^t}{\mu_{dx}}. \tag{23}$$

(c) *Withdrawal conditions*: If the agent exhausts its capital or one of any goods, then it withdraw from the market:

$$M_d^t = 0 \vee G_{dx}^t = 0. \tag{24}$$

3.4. Intermediate agent

Intermediate agent corresponds to auctioneer in e-market place, and provides match-making environment for the attendees. The intermediate agent has transactional scope, and the scope is dynamically spread followed by logistic function:

$$V_i^t = \frac{A}{2} \cdot \frac{\exp(C_{V_i} t)}{1 + \exp(C_{V_i} t)}, \tag{25}$$

where A is the diagonal length of the market, C_{V_i} the constant value.

All the agents inside the scope are considered as applicants for match-making algorithm. We applied four-heap algorithm [12] for the match-making process shown in Fig. 2.

All the applicants are divided into four heaps, and each agent in $S_{\rm in}$ and $B_{\rm in}$ successfully is able to find its partner in this match-making field. The behaviour of intermediate agent is as follows:

Step 1: Call for the market to all the agents inside the scope.

Step 2: Collect the information from all the agents who attend the market by their own decision.

Step 3: Proceed the match making based on four-heap algorithm. Clearing price between producer agent s^* and consumer agent d^* ($MP^t_{s^*xd^*}(= MP^t_{d^*xs^*})$) is calculated as next equation:

$$MP^t_{s^*xd^*}(= MP^t_{d^*xs^*}) = \frac{P^t_{s^*x} + P^t_{d^*x}}{2}. \tag{26}$$

Step 4: Report the transactional results to all the applicants.

Step 5: Negotiated transactions are finally carried out in VM based on the match-making process.

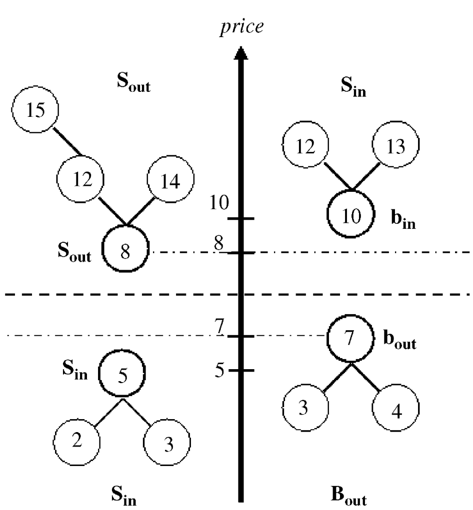

Fig. 2. Schematic diagram of bids arranged in the four heaps.

4. Experimental results

We describe several results attained by computer simulation, and clarify some distinctive characteristics of the price dynamisms in VM. Additionally we describe the relationship between micro agent behaviour and macro market structure, so-called micro–macro loop, which is observed generally in adaptive complex systems.

4.1. Experimental conditions

We constructed small but principle complex VM as a basic study to analyse distinctive characteristics. The parameters are shown in Table 1.

U(min, max) and N(Ave, σ^2) mean uniform distribution and normal distribution, respectively, in Table 1. Simulation trial is 100 times at each result described in this paper.

4.2. Price dynamism and scope effects

Dynamic transactional price transition of goods 1 is shown in Fig. 3 (producer) and Fig. 4 (consumer). These figures show that the converged transactional prices are emerged in the VM, although it has no positive convergence mechanism which Walras market has. The converged prices are acquired through adaptive micro–macro interactions between agents and market, and that means the complex VM successfully attains practical market mechanism in reality. There happens some autonomous selection amongst agents, and only the appropriate number of agents is able to survive in this market according to the power balance between supply and demand.

The VM with complex systems concept is not stable in its nature, and these prices are not always converged.

Table 1
Experimental parameters (initial)

Producer agent (s)		Customer agent (d)	
Capital: M_s^0	10 000	Capital: M_d^0	20 000
Price: P_{sx}^0	U(400, 500)	Price: P_{dx}^0	U(450, 550)
Production (goods 1): O_{s1}^0	10	Stock: G_{dx}^0	N(50, 25)
Production (goods 2): O_{s2}^0	15	Consumption (goods 1): μ_{d1}	5
Cost (goods 1): C_{O_s1}	5	Consumption (goods 2): μ_{d2}	6
Cost (goods 2): C_{O_s2}	4	Sales income: C_{MD}	5000
π	10		
Fixed cost: C_s	100		

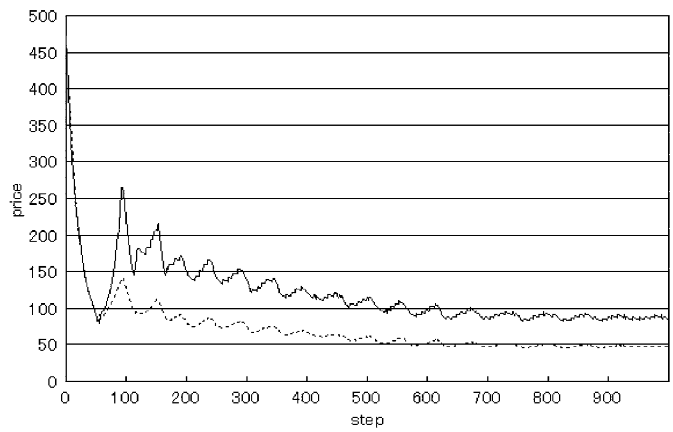

Fig. 3. Price of product 1 (producers).

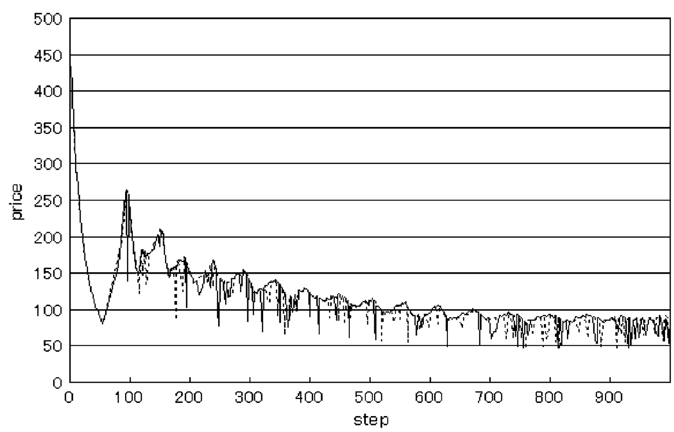

Fig. 4. Price of product 1 (customers).

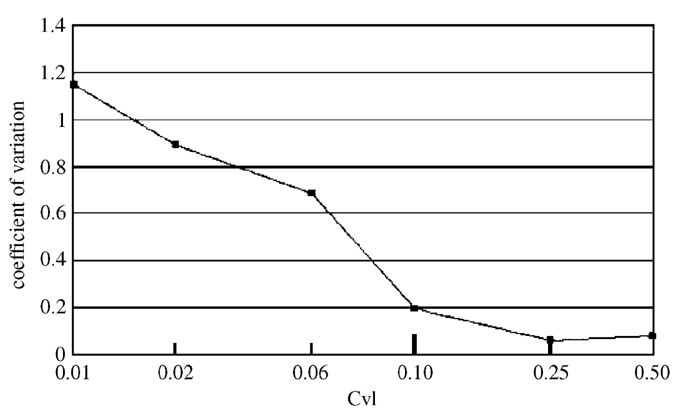

Fig. 5. Coefficient of variation.

A number of simulation trials showed us that the transactional scope of intermediate agent has great effects on the price stability. Fig. 5 shows the relationship between the scope parameter and coefficient of variation of the converged transactional price (goods 1).

It is obviously shown that the price is stabilised as (C_{V_i}) increases, i.e. the scope enlarges rapidly. Especially (C_{V_i}) is around 0.1, the coefficient of variation decreases sharply, and the price stability is improved rapidly. The fact implies that the relaxation of the constraints on agent visibility draws the VM with complex systems closer to classical Walrasian market, which has positive convergence mechanism inside. It has been confirmed that the price convergence of the proposed VM is manageable by the scope factor.

4.3. Micro to macro analysis

Micro–macro loop is one of the important phenomena in complex systems. As the basic study we try to clarify the influence of micro agent behaviour into macro market characteristics in this section. As the preparation of the analysis, we introduce an indicator called autocorrelation value shown in Eq. (28), which is widely used to analyse the time series data.

Suppose an observed time series data are

$$x(t), \quad t = 0, 1, 2, \ldots, N \tag{27}$$

then autocorrelation value is formulated as follows:

$$\phi(\tau) = \frac{\sum_{t=0}^{N-\tau} (x(t) \times x(t+\tau))}{\sum_{t=0}^{N-\tau} (x(t)^2)}. \tag{28}$$

We tried to analyse the relationship between the market stability and consumer agent behaviour. Simulation results on the autocorrelation values in $\alpha_{dx} = 0.001, 0.02, 0.05$ are shown in Figs. 6, 7 and 8, respectively.

As the summary of these results, Fig. 9 shows the comparison of each experimental condition in Figs. 6–8.

We have observed several distinctive results from those simulation analyses as follows:

- If the price modification parameter of consumer agents (α_{dx}) is small $(=0.001)$, the autocorrelation value decreases gradually with large and wide fluctuations. It is difficult to emerge stable transactions due to dull response of consumer agents for price modifications.
- On the contrary, if the price modification parameter of consumer agents (α_{dx}) is large $(=0.05)$, the autocorrelation value converges into a negative value. Producer

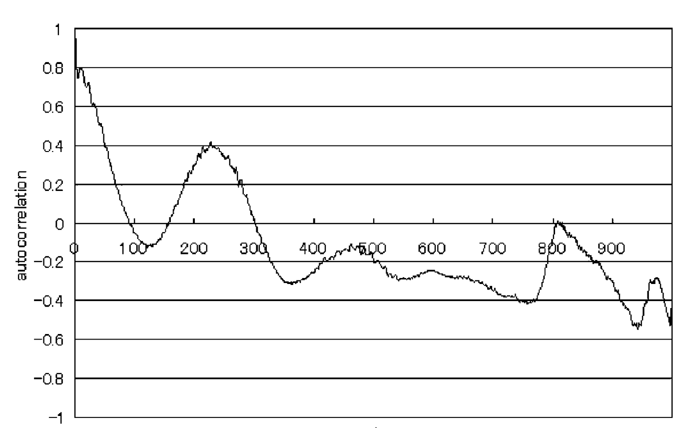

Fig. 6. $\alpha = 0.001$.

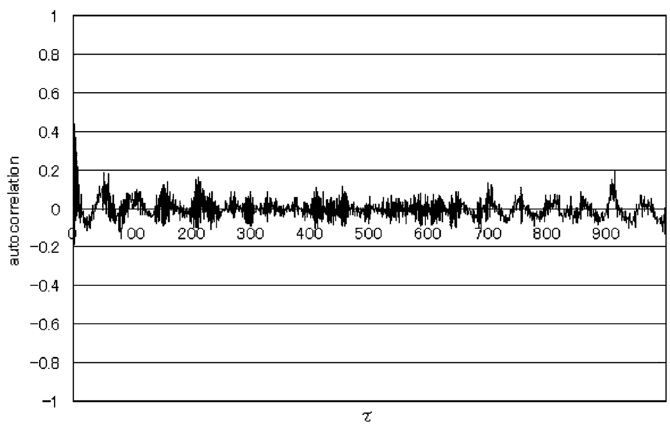

Fig. 7. $\alpha = 0.02$.

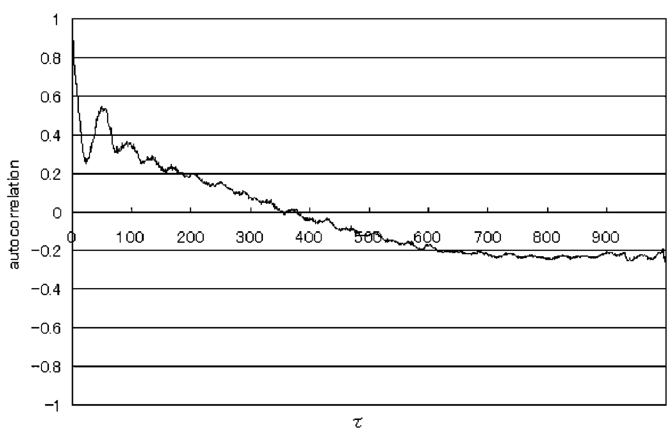

Fig. 8. $\alpha = 0.05$.

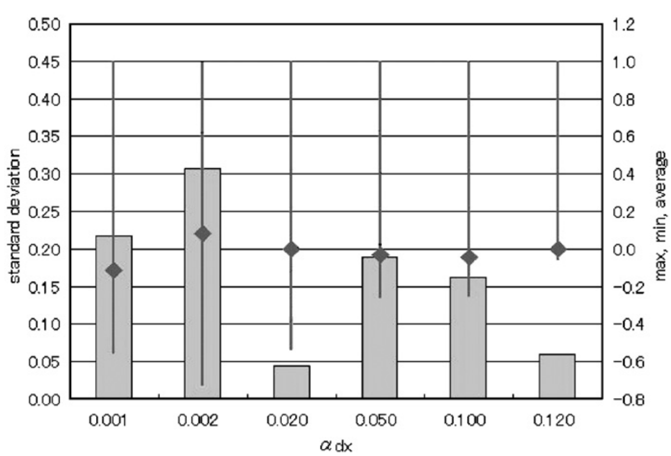

Fig. 9. Autocorrelation value.

agents are unable to follow the rapid price modification of consumers, and that causes to shrink the market.

- If the price modification parameter (α_{dx}) is moderate ($= 0.02$), the autocorrelation value converges around 0 with small fluctuations. The appropriate behaviour of consumer agents on price modification emerges stable market regardless of the positive convergence mechanism of the market model.

4.4. Sensitive dependence on initial conditions

Finally we analysed the proposed market in terms of the dependency on initial conditions, which complex systems have in general.

Figs. 10 and 11 illustrate the final budgets (at $t = 1000$) of producer agents and customer agents, respectively, in the market. (x, y) means the existing position of each consumer agent in this figure. It has obviously observed that the budget distribution is very large, and the budget difference is deeply connected to the initial conditions of the market, such as positions, budget and price modification parameter. An accidental small difference at first emerges great diversity as the consequence of agent interactions finally.

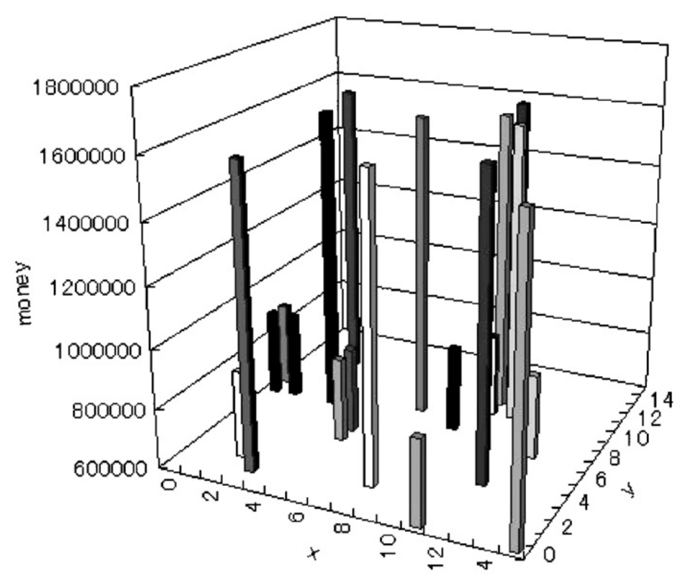

Fig. 10. Final-landscape (producers).

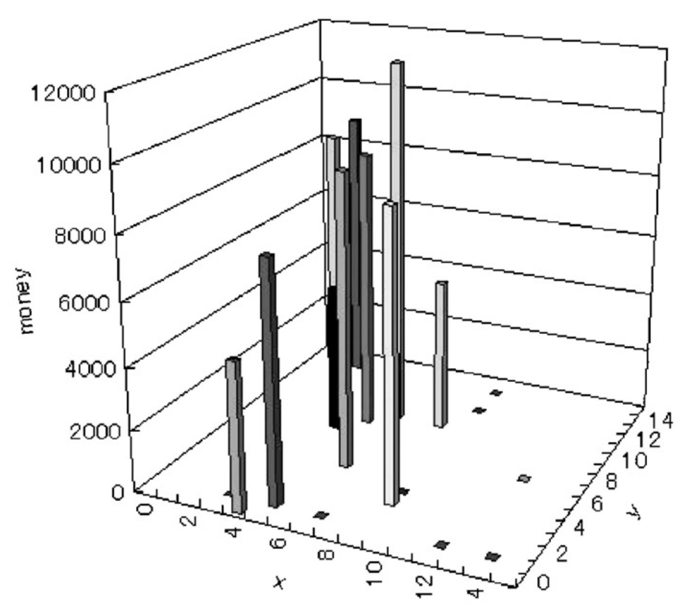

Fig. 11. Final-landscape (customers).

We have confirmed that our VM obtains sensitive dependence on initial conditions (SEDIC).

5. Conclusions

In this study, we focused on the subject about how prices of the goods are decided and how the goods are dealt in among the enterprises that compose the supply chain. Then we have constructed an ''artificial market'' in computer, and the macro dynamism of the market has been analysed from the micro point of view. The artificial market has been constructed based on the model of economics of complex systems, which has several unique features compared with conventional Walras market.

At first, the basic market model, which abstracts and simplifies an actual market, has been defined and constructed, and we have simulated this model. Some distinctive characteristics of the price dynamisms have been observed in this simulation, and the decision mechanism on the market price has been analysed by the behaviour of each agent. It has been clarified that the price is fully converged in some cases, although the market does not have specific mechanism for the convergence that Walras market holds.

Additionally, we have found out that the spread speed of intermediate agent's view has affected market's activity and stability. And SEDIC has been observed in this model. Moreover, it has been observed that the balance of rising/lowering price parameters between producer agents and customer agents is important to stabilise market.

Our obvious extension of this research is to enhance the VM into multiple goods and markets environment so as to apply the VM concept into SCM with reality. Our interests are on the similarities between the two market models in their dynamism, and the markets stability related to the spread speed of intermediate agents' view in those VM models. Obtaining some adaptive behaviour of three kinds of agents is another interest with the viewpoint of complex emergent systems.

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