A Poly-Agent System Analysis on the Evolution of Environmentally Sound Behavior; the Role of Information Provision and the Spillover Effect of Knowledge

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Abstract

Recently, green consumerism and green marketing have been increasing. Information provision policies such as environmental labeling and environmental ISO are regarded as one of the factors that raise the public's concern for environmental issues. We investigate roles of information provision policies on environmentally sound behavior, using a computational agent-based model. This paper also shows effects of knowledge stock; the spread of reputation for provided information into a society.

In the models of this paper, a method of poly-agent system analysis is applied in the framework of a traditional economic model. This method can introduce more complicated situations into models than the conventional theory has ever treated.

In simulations of our models, one finding is that information policies alone are not enough to heighten agents' concern in a society. The knowledge of reputation for provided information is an important factor. The other finding is that knowledge spillover affects agents in neighboring communities only in the presence of information provision policies.

1. Introduction

The 1990s is called "The Decade of the Environment," and has seen a marked increase in the public's concern for environmental issues. The public has been seeking to lessen the environmental impacts of daily activities. The number of "green" consumers, who buy and use environmentally less harmful products, is increasing. On the other hand, marketers in both developed and developing countries exhibit great variety in environmental performance. For example, in developed countries, some firms disclose their environmental reports, some introduce environmental management system and some of their products are labeled environmentally sound products by the third certification authorities. In developing countries, despite the weakness of regulatory framework by governments, some plants overcomply with domestic emissions standards and satisfy OECD levels [1].

What are the conditions under which the environmentally sound behavior as mentioned above continues to advance? How would the agents' "green" activities in a certain community affect neighboring communities? Is it possible that all the society shifts "green"? These questions have gained increasing importance among policy makers and are likely to continue their rise to prominence in the coming years.

It is reported that disclosure policies, such as environmental labeling like Eco-Label in Japan, the environmental ISO, and the Toxic Release Inventory in the United States, play an important role on pollution control policy [1][2]. The disclosure policies are attempts to increase the availability of information on pollution to the public. Those policies are expected to lead the public into having stronger concern for the environment and altering the behavior for the better. Tietenberg [2] gives a survey of practical analyses on the roles of disclosure strategies. But few theoretical and computational studies have so far been made. It is for this reason that traditional economic models don't include the process of altering agents' preferences, which is significant for understanding the social phenomenon as treated in this paper.

The purpose of this paper is to examine roles of information provision policies on environmentally sound behavior using a computational agent-based model, and to find conditions for the greener society. A poly-agent system approach presented in Zaima [3] is extended in this paper.

The rest of the paper is organized as follows. The outlines of the basic model is described Section 2, one-community

cases and two-community cases are studied in Section 3 and 4, respectively, and conclusions are discussed in Section 5.

2. The Outlines of the Basic Model

Models in this paper are based on Zaima [3]. In the model, a method of poly-agent system analysis is applied in the framework of a traditional economic model. The basic concept of the poly-agent system is as follows. Each agent in a considering system has a subjective internal model. Each agent acts referring his/her internal model and the others' and then modifies his/her activities. The considering system consists of a large number of those autonomous agents. Poly-agent system analyses study on the emergency that the interaction of micro autonomous agents causes a macro pattern of the system.

The outlines of the model in this paper can be schematized as shown in Figure 1. Each agent has a level variable called "environmental consideration level" which represents the degree of the agent's environmental concern. The environmental concern in this model includes the following factors; to what extent the agent worries about environmental issues, how he/she wants to take actions in the community for the environmental conservation, and to what degree he/she wants to lessen environmental impacts of the goods he/she produces or purchases. The internal model of an agent consists of a level variable and the adjusting system. Each agent acts in the community and in the market, revealing his/her own environmental consideration level. Each agent refers each other and adjusts the level variable according to his/her own adjusting system in a short cycle. Each agent adds his/her utility/profit for a long cycle, refers it each other, learns what adjusting system brings him/her better utilities/profits, and then modifies the action. In this model the decision making of any agent at each time is optimal under the restriction of the agent's internal model and the leaning by any agent in a long cycle should be rational.

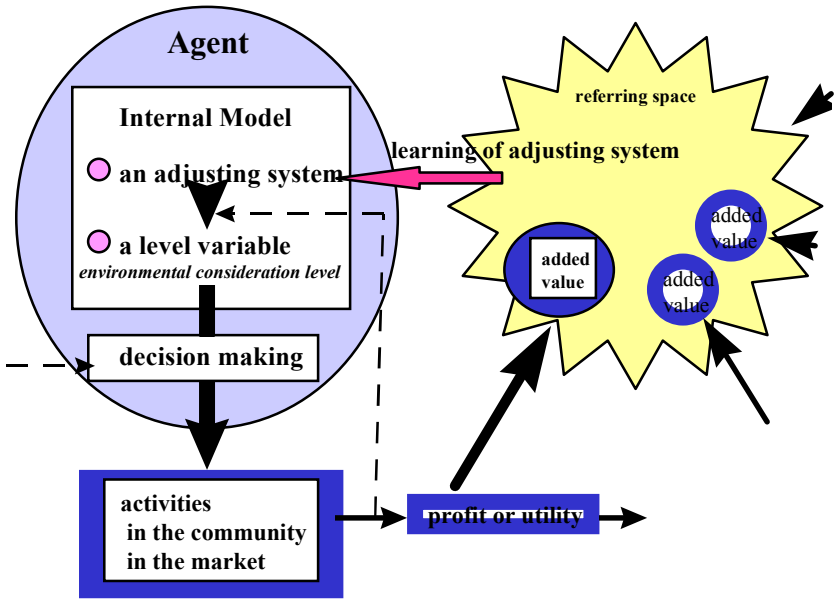


Fig.1 Outlines of the Model

In this model there are two classes of agent, that is, "consumer" and "firm." The numbers of agents are supposed to be constant. At any time, each agent has an environmental consideration level. In our simulations this level variable is set 0 or natural number not exceeding 5. The larger the value, the higher the environmental concern. At the initial time the value is fixed to 0. A slight rate of consumers raises levels at time 1. This paper examines a dynamics of the system caused by such a slight change.

Each agent takes an action in the community in proportion to his/her level. It takes costs to act for protecting the environment and the costs are proportion to the extent of environmental actions. For simplicity, we suppose this economy (community) has a single good. Any consumer reveals his/her environmental consideration level as environmental preference for goods in the market. Any firm knows them and supplies goods with the level not exceeding his/her level. The production cost is proportion to the environmental consideration level of goods. Any consumer knows all of the existing levels of goods and chooses goods with the level not exceeding his/her level under budget constraint. In this paper, it is assumed that the budget is constant and the same for all consumers and we assume no stocks of goods in the market, for simplicity.

Figure 2 represents some examples of adjusting systems. In this model, any agent consider the following three factors in altering his/her level. It is assumed that all agents know the average value of community activities for each class of agent. Each agent subtracts the average value from his/her own and considers the sign, that is, plus, zero, or minus. In Figure 2 those factors concerning the same class and the other class are called Rhomo and Rhetero, respectively. And at any time each agent subtracts the amount of supply/demand from the previous amount and considers the sign, that is, plus, zero, or minus. In Figure 2 this factor is called RX.

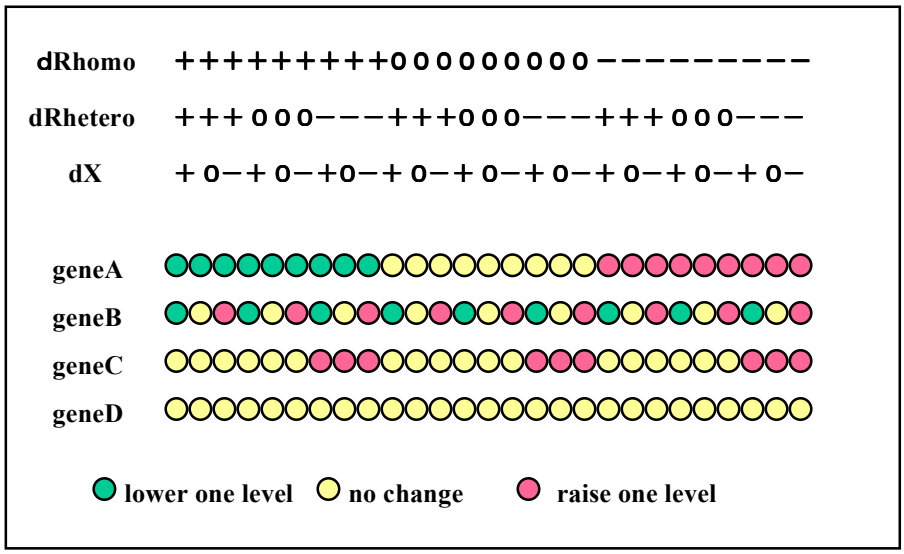


Fig.2 Some Examples of Adjusting Systems

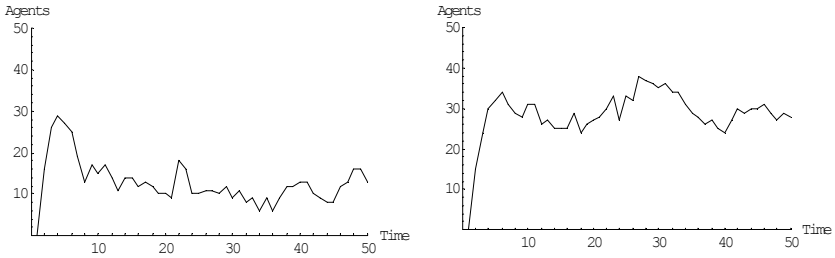
In this paper environmental information policies are described using structural parameters. In our simulations, the implementation of those policies is set to lower the costs of community activities and to heighten utility of consumers who buy goods with upgraded environmental levels. See Zaima [3] for details of the model.

3. One-Community Cases

3.1 Locking in the Lowest Level

Figure 3 shows changes of the number of agents with environmental consideration levels 1 and more for 50 periods, in which (a) is a simulation for a no-policy case and (b) is for a policy case. It indicates that information provision policies seem available for a short run because in the policy case the number of agents with higher concern is larger than that in the no-policy case.

Changes of Number of Firms with level 1 and over



(a) no information policy case **(b) information policy case**

Fig. 3 Effects of Information Policies for 50 Periods

For a long run, however, all agents are locked in level 0 regardless of the existence of policies, as shown in Figure 4. Figure 4 is a 600-period simulation for a policy case.

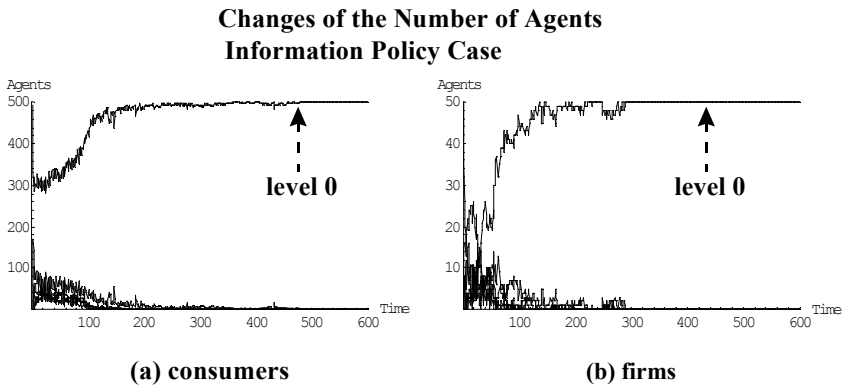


Fig. 4 Locking in Level 0 for 600 Periods

An explanation of this result is as follows. There exist some agents who are affected by the slight change caused at the period one and raise their level variables. When the number of consumers with upgraded levels is not enough for the number of firms with upgraded levels, firms don't gain larger profits than they earned before. And therefore, they get to learn adjusting systems by which level variables are shifted downward. On the other hand, any consumer with upgraded level, who finds no firms with the same level variable as his/hers, can't enjoy higher utility despite of having raised the level. And therefore, he/she also gets to learn adjusting systems by which level variables are shifted downward.

We also simulate a mixed-policy case, that is, information provision policies mixed with a penalty-subsidy policy, in our simulation, penalty for firms with level 0 and subsidy for firms with level 1 and more. Though for a short run the penalty-subsidize policy seems to have effects on firms' attitudes, for a long run the level of all agents converge 0.

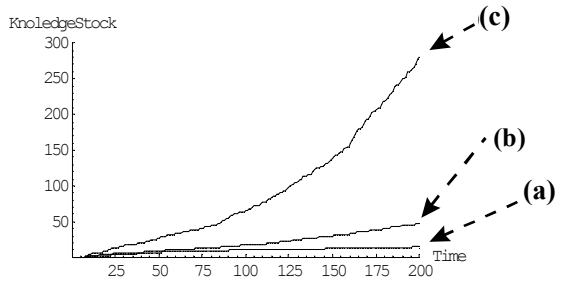
3.2 A Role of Knowledge

The results in the previous section indicate that information provision policies don't work well by themselves. It seems contradictory to a conventional thinking about environmental information provision. The implementation of information provision policies is supposed to bring consumers higher utilities. Consumers are expected to find that purchasing of environmentally sound goods benefits them. And firms are expected to respond green consumers' demand and therefore, those policies are expected to control marketers indirectly. However, such a discussion doesn't take the rate of learning into consideration. Even under the implementation of information policies, if the rate of the learning that consumers shift upward is slower than the rate of the learning that firms shift downward, those policies become unavailable. As a result, all agents are locked in the lowest level.

In this section, we create a situation in which there exist agents with higher environmental consideration levels for a long run. Consider a society where someone gives some reputation concerning provided environmental information and they are accumulated as a knowledge stock. In this model, a slight rate of agents with the highest level 5 gives a reputation that any agent had better raise his/her environmental consideration level. Even if such a reputation spreads in the society, the response is intrinsic for each agent. Each agent has his/her own threshold for the knowledge stock. A certain agent who finds that the amount of knowledge stock in the society becomes larger than his/her threshold has an incentive not to lower the environmental consideration level. The model described in Section 2 is extended in order to simulate this situation.

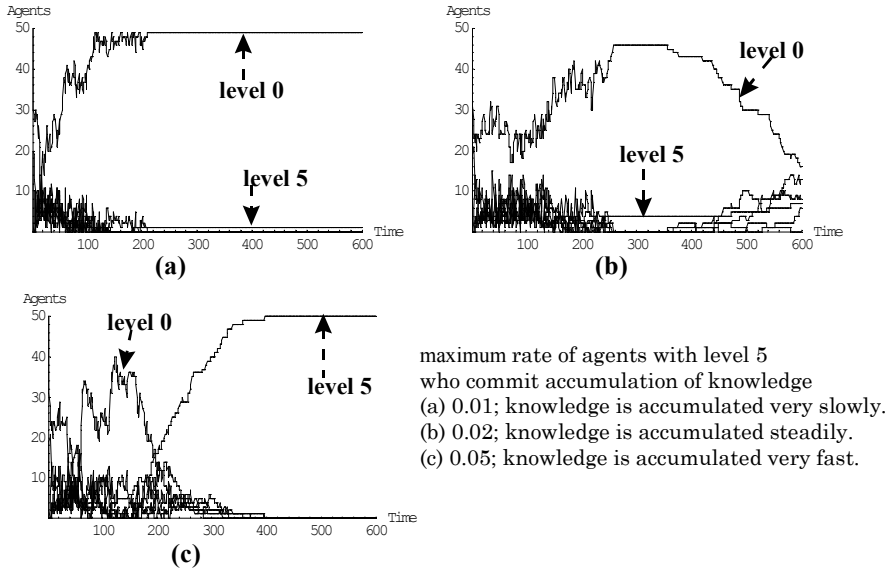
We simulate a several cases with different rates of agents with level 5 who commit the accumulation of knowledge. Figure 5 shows three patterns of the accumulation of knowledge stock in our simulations. For three cases represented as (a), (b) and (c) in the figure, the maximum rates are set as 0.01, 0.02 and 0.05, respectively. It is clear that the speed of accumulation is slow when the rate is small.

Figure 6 shows changes of the number of firms with each level value concerning three cases in Figure 5. In the case of (a) in which knowledge accumulation is extremely slow, all agents except one firm are brought back to zero. This represents a situation where there exist some consumers with higher environmental concern and a slight part of firm responds to the green consumers' demand. In this case consumers with levels higher than 1 are obliged to buy the goods with level 1. In the case of (b) in which knowledge is accumulated steadily, multiple levels coexist in the society after 600 periods. This represents a situation where firms exhibit a great variety in environmental performances. In the case of (c) in which knowledge is accumulated very fast, the levels of all agents reach the highest level 5. This shows that a society can shift green if reputations for provided information continue to spread enough. Some results obtained in this section are reported in Zaima [4], too.



maximum rate of agents with level 5
who commit accumulation of knowledge
(a) 0.01 (b) 0.02 (c) 0.05

Fig. 5 Three Patterns of Accumulation of Knowledge Stock



maximum rate of agents with level 5
who commit accumulation of knowledge
(a) 0.01; knowledge is accumulated very slowly.
(b) 0.02; knowledge is accumulated steadily.
(c) 0.05; knowledge is accumulated very fast.

Fig. 6 Effects of Knowledge Stock on Firms' Behavior

4. Two-Community Cases

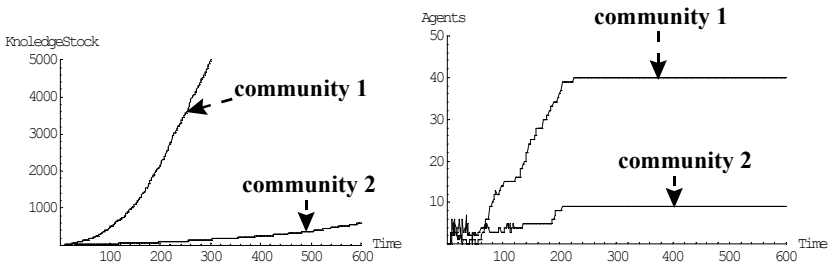
4.1 Spillover Effect of Knowledge

In this section, we extend our model to study multiple community cases. In our simulations we consider two communities with different speed of knowledge accumulation. The maximum rates of agents who appreciate provided information and commit knowledge accumulation are set as 0.05 for community 1 and 0.02 for community 2. In simulations in this section, environmental information policies are implemented.

First, we consider a case in which knowledge doesn't spillover between community 1 and community 2. Figure 7(a) shows processes of accumulation of knowledge stock and Figure 7(b) shows changes of the number of firms with level 5.

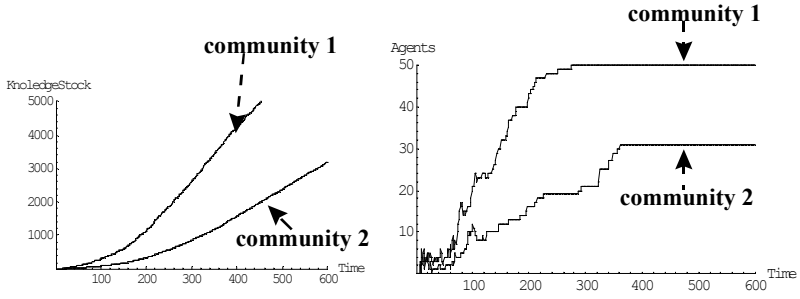
Next, we consider a case in which there exists spillover of knowledge between the two communities. The rate of spillover of knowledge stock is set as maximum 0.2. Figure 8(a) and 8(b) shows processes of accumulation of knowledge stock, and changes of the number of firms with level 5, respectively.

Making a comparison between Figures 7 and 8, the knowledge accumulation of community 2 in the spillover case is faster than that in the no spillover case. The knowledge spillover from community 1 affects environmental behavior of agents in community 2. As a result, in the spillover case the number of firms who raise levels becomes greater than that of firms in the no spillover case. It means that the spillover effect of knowledge is an important role on the change of social structure into the higher environmental conscious society.



(a) knowledge accumulation **(b) changes of number of firms with level 5**

Fig. 7 A Case of No Knowledge Spillover



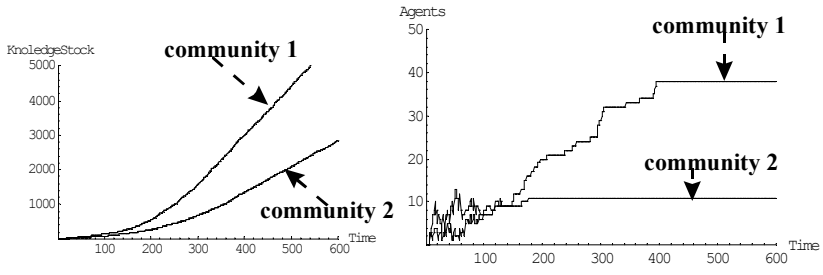
(a) knowledge accumulation **(b) changes of number of firms with level 5**

Fig. 8 Spillover Effects of Knowledge

4.2 A Role of Information Provision Policies

In this section we examine again a role of information provision policies. In simulations in this section, information provision policies are implemented only in community 1. The conditions except policies are the same as in the previous section. That is, knowledge spills over between two communities. Figure 9(a) shows processes of accumulation of knowledge stock and Figure 9(b) shows changes of the number of firms with level 5.

Existence of Spillover of Knowledge between Two Communities
No Information Policies in Community 2



(a) knowledge accumulation **(b) changes of number of firms with level 5**

Fig. 9 Role of Information Policies

Making a comparison between Figures 8 and 9, though the patterns of knowledge accumulation of two communities are similar in both figures, the number of firms of community 2 who raise levels are greater in the policy case than that of firms in the no policy case. The reason for this is as follows. It takes much cost for firms with higher levels to take an environmental action in the community without information policies. As a result, therefor firms don't have much

incentive to raise levels even in the presence of knowledge spillover. Therefore it means that spillover effect of knowledge decreases unless information policies are introduced.

5. Conclusion

Models in this paper were extensions of Zaima [3], which applies methods of a poly-agent system analysis to an economic theoretical framework. We could introduce more complicated factors of decision making into our models than the conventional theory has ever treated.

In this paper, we investigated the roles of environmental information policies and the effect of knowledge stock. From the results of Section 3, we found that information policies alone were not enough to heighten agents' concern in a society. The knowledge of reputation for provided information was found to be an important factor. From the results of Section 4, we found that knowledge spillover affected agents in neighboring communities only in the presence of information provision policies.

All of these two facts amount to saying that knowledge is a complement of information provision policies. We can explain about the property of the complement as follows. In our models agents choose environmental consideration levels and learn adjusting systems. Information provision policies affect agents in the choice of level variables, bringing consumers higher satisfaction. And through green consumers' choice of goods, firms are expected to become green firms and non-green consumers are also expected to find green firms. From this point of view, information provision policies are expected to affect agents in the learning of adjusting systems. In other words, we can say that information provision policies include a mechanism for indirect learning of adjusting systems. On the other hand, the knowledge of reputation for provided information affects agents directly in the learning of adjusting systems, giving agents the incentive not to lessen the levels. Thus we can say that the spreading of knowledge includes a certain kind of mechanisms for direct learning of adjusting systems. As explained in Section 3, the indirect learning through information provision policies often end in failure. We insist on the importance of the direct learning through the spread of knowledge, in the failure of the indirect learning through policies.

Concerning the role of knowledge, years of study for family planning of United Nations provide a typical example. Our results also indicate that knowledge is significant in the environmental policy context. The knowledge means correct reputation about provided information. Environmental education is a kind of policies for giving people some knowledge to understand the provided information correctly. We see that environmental education is necessary to be implemented for complement of information policies.

Deguchi [5] shows a replicator dynamics model concerning the effect of knowledge on the behavior of agents. We can analyze the results obtained in this paper theoretically with an extended model of Deguchi [5]. See Zaima and Deguchi [6] for details.

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