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Physica A 323 (2003) 663–676
PHYSICA A
www.elsevier.com/locate/physa

Division of labor as the result of phase transition

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Received 15 November 2002

Abstract

The emergence of labor division in a multi-agent system is analyzed by the method of statistical physics. We consider a system consisting of N homogeneous agents. Their behaviors are determined by the returns from their production. Using the Metropolis method in statistical physics, which in this model can be regarded as a kind of uncertainty in decision making, we constructed a Master equation to describe the evolution of the agent's distribution. We introduce an earning function including learning by doing to describe the effect of technical progress and a formula for competitive cooperation. And we also introduce two order parameters to characterize the division behavior. The model gives us the following interesting results: (1) As a result of long-term evolution, the system can reach a steady state. (2) When the parameters exceed a critical point, the division of labor emerges as the result of phase transition. (3) Although the technical progress decides whether or not phase transition occurs, the critical point is strongly affected by the competitive cooperation. From the above physical model and the corresponding results, we can get a more deeply understanding about the labor division.

PACS: 87.23.Ge; 05.90.+m; 89.90.+n

Keywords: Division of labor; Statistical physics; Phase transition; Metropolis method

1. Introduction

The economic system is no doubt a many-particle system—it can be viewed as a collection of numerous interacting agents. So it is possible that the methods and concepts developed in the study of strongly fluctuating systems might yield new results in this area. In fact, in the past decades the approaches from statistical physics have

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0378-4371/03/$ - see front matter © 2003 Published by Elsevier Science B.V.
doi:10.1016/S0378-4371(03)00053-0

been applied in economics and many interesting results, including empirical laws and theoretical models, have been achieved (see Refs. [1–5] as a review of Econophysics). In all these studies, a great deal of research is on the agent-based modelling and related non-trivial self-organizing phenomena. In the economic system, the agents learn from each other, and their activities may be influenced by others' actions. These interactions between agents may be simple and local, but they may have important consequences related to the emergence of the global structure. To understand the mechanism behind these innovation phenomena, the methods and concepts in phase transitions and critical phenomena are helpful; for instance, in the study of majority and minority game [6,7], opinion formation [8], and computational ecosystems [9].

In this paper, we focus on the formation of division of labor. Roughly speaking, an economic organizational pattern is said to involve division of labor if it allocates labor of different individuals to different activities. Hence the specialization of individuals and the number of professional activities are the two sides of division of labor [10]. It is a common functional organization observed in many complex systems, and it is a fundamental way to improve efficiency and utilization so as to get global optimization for the system. In order to investigate the mechanism behind the formation of labor division, we have constructed a simple model with many interacting agents. Every agent has only two kinds of tasks, namely A and B. We describe the level of specialization of agent by his working-time share spent on producing A or B. Each agent makes their decisions for working-time in different tasks, and receives payoffs according to their and other agents' choices. The agents can adapt by evaluating the performance of their strategies from past experience so as to get maximum returns. The returns for any agent is determined by its production with endogenous technical progress-through the mechanism of learning by doing, and its cooperation with other agents. Just like the Hamiltonian in statistical physics, the payoff function determines the behavior of the agent in the economic system. Because of the bounded rationality and incompleteness of information in the system, we have introduced a parameter, named social temperature T (in the model, we have absorbed the $\beta = k_B T$ into the other parameters. Such an approach is traditionally used in Statistical Physics, for example, let $H' = \beta H$, so the new J in Hamiltonian of Ising model means βJ actually.), to describe the degree of randomness in decision-making. Then we assume that the system should obey the canonical ensemble distribution, that is, the probability $P(\vec{x})$ of a microstate $\vec{x}$ is proportional to its 'Boltzmann factor' determined by the total returns of the microstate $\vec{x}$:

$$P(\vec{x}) = \frac{e^{+\beta E(\vec{x})}}{\int e^{+\beta E(\vec{x})}\, d\vec{x}} . \tag{1}$$

Then using the Metropolis simulation method, we can get a Master equation to investigate the evolution of the system. With the continual change of system parameters, we have found a so-called 'social phase transitions' phenomenon related to the emergence of labor division.

The model is defined in Section 2. The economies of specialization are introduced by increasing returns from learning by doing. And the economies of complementarity is described by an additional payoff from the combination of two products. Section 3 gives