Physica A 506 (2018) 613–624

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

On the mechanism of phase transitions in a minimal agent-based macroeconomic model

Ye Sun [a], Yu Chen [b,*]

[a] Graduate Program in Sustainability Science—Global Leadership Initiative, Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa City 277-8563, Japan

[b] Department of Human and Engineered Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa City 277-8563, Japan

HIGHLIGHTS

- Phase transitions are found in a modeled economic system.
- Mechanisms of phase transitions with two control parameters are theoretically analyzed.
- Demand–supply and debt ratio gaps in two subgroups of firms cause the transitions.
- Undiminished demand–supply gap in oversupplying firms two extreme phases.
- Diminishing debt ratio gap in indebted firms causes clustering and the crisis phases.

ARTICLE INFO

Article history:
Received 7 November 2017
Received in revised form 20 March 2018
Available online 22 April 2018

Keywords:
Agent-based model
Crisis
Phase transition
Non-equilibrium
Cluster
Self-organization

ABSTRACT

We conduct a theoretical analysis for Mark0, which is a minimal macroeconomic agent-based model, to understand the emergence of phase transitions in the modeled economy. We identify directly the essential components and processes relating to specific mechanisms of all phase transitions in the system. The primary finding is that though the entire economy seems to reach equilibrium as the firms seem to be randomly distributed, some subgroups of firms are undergoing irreversible non-equilibrium processes. In particular, the irreversibility is rooted either in the undiminished demand–supply gap among a group of oversupplying firms, or in the diminishing debt ratio gap among a group of indebted firms. Whereas the undiminished oversupplying firms drive the economy to extreme states overtly, the indebted firms evolve into a cluster inside the economy covertly due to the diminishing debt ratio gap in this subgroup. In the latter case, it is further shown that the self-organized subgroup is steadily driven to the phase boundary, at which the random factors embedded in the model trigger a cascade of default events and cause the crash of system.

1. Introduction

Recently, agent-based models (ABM) have become the focus of interests in economics to re-examine the fundamental assumptions and conclusions of macroeconomics. The two main advantages of ABM, differing itself from the traditional

* Corresponding author.
E-mail addresses: yesun@s.k.u-tokyo.ac.jp (Y. Sun), chen@edu.k.u-tokyo.ac.jp (Y. Chen).

https://doi.org/10.1016/j.physa.2018.04.019

general equilibrium model and the method including the rational representative agents, are discussed in details in [1–3] and summarized as the following two aspects:

Emergent phenomenon. Economy is a complex system, the aggregate state of which often exhibits unexpected patterns totally different from the individual behavior. With ABM, the emergence of complicated phenomenon at the macro-level can be studied thoroughly by tracking back to the relatively simpler interactions on the micro-level based on the behavioral rules of individuals.

System description. It is easier to understand and describe the behaviors of economic individuals than those abstract principles governing the whole system. ABM sketches the system in a bottom-up manner and through the description of individual behavior rules, which makes it a natural and fundamental modeling approach of a complex system.

Besides these two main advantages, in our opinion and based on [4,5] as well, we add one more benefit for ABM:

Econophysics-oriented modeling. Physics, especially in statistical physics and gas kinetic theory, has a long history in dealing with complex systems consisting of a large number of elements. In this sense, ABM with computer simulations could be regarded as an easy realization of physical systems. On the other hand, many theoretical tools and concepts in physics are helpful to understand ABM well and give the prediction of the model behavior in the parameter space, such as non-equilibrium phase transition, irreversibility, self-organization, etc. Therefore, ABM integrated with tools from econophysics has become a natural laboratory for theoretical socioeconomic studies.

Developed in the European CRISIS project, Mark0 is a typical macroeconomic ABM with the features illustrated above, which focuses on solving the complexity for systemic instabilities [5]. Because Mark0 only treats firms as individuals, which produce only one type of products to form an economy with households and a virtual bank, it should be the minimal setting for the maintenance of the economic activities. Therefore, it is not unnatural that Mark0 can be considered as a minimal agent-based model to the modern complex economic system.

Previous computational studies on Mark0 have achieved several important results, especially the discovery of multiple phase transitions among four economic states [5,6]. The four distinct phases are named as full unemployment (FU), residual unemployment (RU), endogenous crisis (EC), and full employment (FE). It is found that FU, FE and RU are different stable states with small fluctuations. On the contrary, EC is an unstable state in which a sudden surge in the unemployment arises from a so-far quiescent full employment economy. Thinking about the computational discovery of phase transitions in Mark0 in depth, however, two important questions are put forward:

-Q1: What dynamic process that the system has been undergoing causes the emergence of EC phase?

-Q2: What are the specific mechanisms responsible for these different phase transitions?

The answers to these questions, in our opinion, would justify the capability of econophysics-oriented ABM in developing a theory. Practically, these answers could also shed new lights on the causes of frequent bursts of crises in the real economy, a mission which traditional macroeconomics failed to complete.

Theoretical studies on Mark0 have already been started, which mainly aim to understand the endogenous crisis phase. For example, in order to understand the synchronization pattern which is an important concept often found in the Kuramoto model [7,8], a metaphoric explanation based on biased random walks is given to EC phase [9] which partially answers Q1, though, the direct mechanism of FE-to-EC transition is still absent. Moreover, the mechanisms of other transition processes such as FU-to-FE, EC-to-RU, are left untouched.

In this study, we perform a direct theoretical analysis of Mark0, which focuses on the clarification of concrete economic conditions of non-equilibrium phase transitions among economic states. Briefly speaking, the answer for Q1 will be more explicitly given, and Q2 is to be answered in this paper.

The paper is organized as follows. In Section 2, after we explain the reasons for choosing a minimal model in developing a theory of the macroeconomic system, we introduce Mark0 and its phase diagram in details. In Section 3, we build our analysis with a particular focus on the existence of irreversible deterministic processes in certain subgroups of firms who share common properties. A clear picture is sketched for the dynamic process during phase transition, and the roles of two control parameters are explained. In Section 4, we discuss the features of our theoretical analysis compared with previous studies, and the direction for future works as well. In Section 5, we summarize our main findings.

2. The minimal model

Since many studies of phase transition like behaviors were revealed in financial markets as well as in socioeconomic systems [10–12], the underlying mechanisms of socioeconomic transition processes have become an important topic relating to the emergence of economic crises. The analysis on a minimal model for an economic system enables us to mathematically derive the dynamics into an economic theory and gain insights on the main mechanism for phase transitions [13,14]. The results obtained from a minimal model can be considered as a general existence inside all other complex models which must include similar basic settings. Similar idea has been applied to develop some baseline ABM for economics as well [15]. In addition, it is problematic to start with a detailed model before the main concerns of the fundamentals of an economic system have been addressed clearly [16]. Methodologically, the generality of a minimal model always permits extensions for more realistic models afterwards [13].

In this paper, the economy in Mark0 is further simplified for easier mathematical manipulations. The labor productivity is a constant unit, thus the production of a firm equals the number of hired labor. Also in the simplest case, the wage rate for the labor is also set as a constant unit. As the result of the simplification, production, labor, and wage are all the same in numerical value for each firm.