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Regulating economic systems in a multi-trait model of self-organized criticality

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Abstract

We study the effect of size-based regulation on an economic system. A multiple-trait model of self-organized criticality is used to simulate the economic system. The major difference of this work from previous studies is that firm's fitness is not characterized by a single number but by M traits. Each trait represents one aspect of the competitiveness of the firm, and firm's size is one of these traits. Major finding drawn from the present study is that the effectiveness of regulations decreases with increasing M, i.e., size-based regulations are less effective when the overall fitness of a firm is determined by more factors.

Keywords: Self-organized criticality; Fitness; Regulation; Economic systems

1. Introduction

The concept and models of self-organized criticality (SOC) have been used in economic studies for more than a decade [1–3]. One stream of this type of research is the use of Bak–Sneppen (BS) evolution model [4] to study the effect of regulations on economic systems [5,6]. To put it in a plain and simple way, BS model utilizes a circular lattice consisting of N sites to represent a ecological system, and assigns a parameter called fitness to each of these N sites. Each site represents a species in the ecological system. Higher fitness means higher probability of survival, while lower fitness implies lower barrier for a species to mutate or to be substituted by a new species. The evolution of the eco-system is simulated as follows. At each time step of evolution, the system is updated by locating the site taken by the species of lowest fitness and replacing that fitness by a random number drawn from a uniform distribution (ranging from 0 to 1). As this update will change the landscape of the ecology, the two neighbors of the updated site will have to adapt to the change by updating themselves through either mutation or substitution by new species—the fitness of these two neighbor sites will be replaced by two new numbers drawn from the same uniform distribution. The system will evolve all by itself into a critical state, at the critical state event of any scale can occur.

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An economic system can evolve in a similar fashion. Cuniberti et al. [5] use the BS model to study the evolution of a market. Cuniberti et al. consider that a firm's competitiveness or the probability of surviving market competition can be characterized by its fitness, and furthermore the firm's fitness is completely determined by the size of the firm. Cuniberti et al. introduce government regulations into the BS evolution model by changing the original Bak–Sneppen updating rule. By arguing that (some) regulations are in favor of small business, the new updating rule requires second update if a site sees its fitness jumps from below to above a threshold (the threshold represents a cutoff of regulation: the regulation is applied only when a firm is of a fitness higher than the threshold). The reason for the second (consecutive) update is explained as that when a small business becomes big business the government regulations will make it harder for the firm to adjust. In the model firms are divided into two sectors: firms smaller than the regulation threshold are in the lower sector (firms in this sector are referred to as small business), and firms larger than the threshold are in the upper sector (firms in this sector are referred to as big business).

In Cuniberti et al.'s work a firm's fitness and size are treated as same without any distinction, therefore a firm's fitness is assumed to be determined solely by its size. In our view, this approach deserves further scrutiny because it is inconsistent with some well-established economics theories, for example, Porter's five force model [7]. In the five force model, a firm's size plays only part of the role to determine the fierceness of the market competition, other factors such as firm's products, asset specificity, and changing conditions of supply and demand also play important role to determine a firm's competitiveness or survivability, or in SOC terminology, fitness.

In this work we will assume that a firm's size determines only $1/M$ of the total fitness, where M is an integer, i.e., a firm's fitness is determined by M equally-weighted factors and firm's size is only one of these factors. If some factors have more weight, they can always be divided into (smaller) sub-factors so that all (final) factors will have equal weights. As it is difficult to quantify exactly how big M should be, the objective of the present study is restricted to examine the effect of size-based regulations when firm size only contributes $1/M$ to the total fitness.

2. Multiple-trait model

Boettcher and Paczuski [8] extend the BS evolution model to allow multiple traits for each species. In the (one dimensional) multiple-trait model, a species is represented by a site on the circular lattice, and for each species the fitness is represented by M traits. A larger trait means better ability to perform a particular task, and a smaller trait implies higher possibility to mutate or to be replaced by a new species. Therefore the fitness of a species is determined by the collection of all M traits. When M is set to unity, the multiple-trait model reduces to the original BS model.

The updating rule of the multiple-trait model can be described as follows. At initial state, random numbers independently drawn from a uniform distribution (ranging from 0 to 1) are assigned to M traits at each site of the total of N sites. At every time step the smallest number among these $M \times N$ numbers is identified and replaced by a new number drawn from the uniform distribution. This event will affect the two nearest neighbors. Each of these two neighbors will have to change to adapt to their new environment: a randomly selected trait will be replaced by a new trait and the new trait is drawn from the uniform distribution.

Now we introduce government regulations into the multiple-trait model, similar to what is done in Cuniberti et al.'s (single-trait) work. The regulations are in favor of small business (as small business enjoys lower tax rate and access to government-backed loans that are available only to small business), therefore when a company grows from small business to big business it will see a stronger drag on it, i.e., it will encounter greater challenge to stay in business. In the multiple-trait model a firm's fitness is represented by a collection of numbers—each number represents one contributing factor to determine the overall fitness of the firm. For example, we can use firm's size, its financial condition (such as cash flow, solvency) and conditions of supply and demand to determine a firm's likelihood of success. In this work we do not intend to identify which factors are more important and what percentage each factor will be in determining the overall fitness. Rather, we assume that there are M factors that are equally important, and firm's size is one of these factors, and we examine the effect of size-based regulations on the overall 'ecological' landscape of companies.