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Boolean network representation of contagion dynamics during a financial crisis

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HIGHLIGHTS

- We model the dynamics of boolean network to apply in financial market.
- The model is applied to the financial crisis.
- The states of network are binary and represent economic variables of countries.
- It is possible to simulate how perturbations in the states of specific nodes propagate to the other nodes.

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ABSTRACT

This work presents a network model for representation of the evolution of certain patterns of economic behavior. More specifically, after representing the agents as points in a space in which each dimension associated to a relevant economic variable, their relative "motions" that can be either stationary or discordant, are coded into a boolean network. Patterns with stationary averages indicate the maintenance of *status quo*, whereas discordant patterns represent aggregation of new agent into the cluster or departure from the former policies. The changing patterns can be embedded into a network representation, particularly using the concept of autocatalytic boolean networks. As a case study, the economic tendencies of the BRIC countries + Argentina were studied. Although Argentina is not included in the cluster formed by BRIC countries, it tends to follow the BRIC members because of strong commercial ties.

1. Introduction

The dynamics of economic crisis, and in particular the phenomenon of contagion, have attracted the attention of various scholars, such as Galbraith [1] who studied the 1929 crash and the consequent propagation of its effects into the financial market. In Bruner and Carr [2] the causes and effects of USA banking crisis of 1907 is treated. It is sometimes referred to as "silent crisis" related to the 1906 great earthquake of San Francisco. According to Bruner and Carr [2], the complex network interactions lead to a spreading contagion that ended up reaching New York. In fact, in the field of Economics and Finance, the network theory and the complexity analysis theory have found many applications, such as those reported in Haldane [3], Haldane and May [4], Nier et al. [5] and Allen et al. [6], among others.

One approach to model crashes or financial crises is to combine network theory with statistical methods to provide quantitative descriptions of the structure of the market and express the interdependencies among the various agents (Onnela

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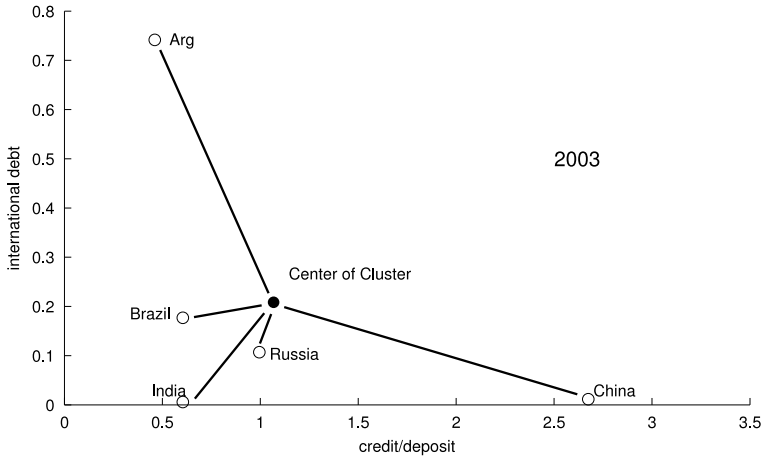

Fig. 1. Cluster of BRIC countries and the position of Argentina in 2003.

et al. [7–9], Estrada et al. [10], Pavlidis et al. [11]). For instance, one can make use of such models to estimate the effects of strengthening or weakening of a particular arc of the network or the absence of a node.

In order to obtain estimates of possible occurrence of bubbles or crashes and the contagion effect of those phenomena, one can use concepts such as those proposed in Sornette [12], Sornette and Johansen [13–15], Johansen [16] and also Johansen and Sornette [17,18]. In previous works, the authors have made use of the Wavelet transform for such purposes (Caetano and Yoneyama [19,20]).

Another interesting concept that can be associated with the contagion effect is the herding. Borrowing the idea of particle swarm from the field of artificial intelligence, the authors proposed a model for herding (Caetano and Yoneyama [21]). Applications of particle swarm approach can be found in Bonabeau et al. [22], Briza et al. [23], Chio et al. [24], Dorigo et al. [25], Garret et al. [26], Kennedy et al. [27], Lee et al. [28], Mezura-Montes [29] and Zhang et al. [30].

In this work, a model is proposed to represent contagion dynamics during a financial crisis by using a network with nodes representing certain patterns of economic behavior. A number of choices dealing with evolving networks, including those employing the concept of artificial life, are available, for instance, in Bagley and Farmer [31], Bagley et al. [32], Farmer et al. [33], Rasmussen [34] and finally Bornholdt and Schuster [35]. Here, boolean networks are adopted (Pozzo [36], Lewis [37]) to model the dynamic interactions among A + BRIC countries (where the letters are Argentina, Brazil, Russia, India and China). More specifically, binary values are used to represent the tendency of each agent to follow a certain economic state that can be considered to be a moving target. Argentina was included in the present study because of its strong ties with Brazil. In a previous work, it was shown that the herding effect can be represented as clusters that move in the feature space (Caetano and Yoneyama [21]). In other words, each country can be represented as a point in a space with each dimension representing a relevant economic variable and are grouped to form clusters. Under crisis, the clusters present movements that can be formally characterized. In 2003, the A + BRIC countries form a cluster as shown in Fig. 1. The movement of approaching the BRIC countries can be seen in Fig. 2. Although Argentina is not a BRIC country, it tends to follow the cluster formed by BRIC countries. In this work, this result is extended using the concept of autocatalytic boolean networks.

2. A boolean network model

A boolean network can be represented by graphs with arcs assuming values {0, 1} when the nodes linked by it have some form of connectivity. For instance, if there is a strong interrelation between a pattern represented by nodes i and j, then the arc between these nodes will have the weight $c_{ij} = 1$, and 0 otherwise.

The boolean networks have already found many applications in finance and economics (Nier et al. [5], Haldane [3], [4], Onnela et al. [7], Onnela et al. [8], Onnela et al. [9]). In the context of this work, the idea is to model the similarities in the economic behavior presented by the various agents which leads to herding.

The nodes in this work are labeled as a binary number, for instance, $(b_1, b_2, b_3, b_4, b_5) = (01011)$ if one considers 5 countries. Each country can be represented as a point in the plane with axis: $x =$ abscissa $=$ relation credit/debt and $y =$ ordinate $=$ external debt. Assume also that the countries associated with bits $b_1, \ldots, b_2$ form a cluster in this plane and the coordinates of the center are $c = (c_x, c_y)$. If the country represented by bit b_i has approached the center of the cluster formed by $b_1, \ldots, b_5$ during a sample time interval, "0" is assigned to it. The verification if a point has approached or distanced from c is made by computing the "distance"

$$d_i = \sqrt{(x_i - c_x)^2 + \left(x_i - c_y\right)^2}. \tag{1}$$