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SELF-ORGANIZED CRITICALITY AND ECONOMIC CRISES

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Abstract. The conventional economic science appears to have ignored some important phenomena of economic systems by treating them as exceptions – namely the *destructive phenomena*. Relying on various widely accepted models and theories that practically avoid the occurrence of *failures*, *depressions*, *crises* and *crashes*, the economic science is incomplete and clearly needs a major reorientation and a change of focus from the *deterministic* to the *holistic* perspective.

This paper is primarily oriented on discovering and understanding the destructive phenomena in economic systems through the *paradigm of complex systems*. Introducing a new economic model based on a connective structure borrowed from neurosciences, interesting behaviour is emerging even for a very simplistic economic system like a distribution network. A new cause for the apparition of economic crises which is unconventional and totally different from the common views is identified and brought to light.

Introduction

The modern economic science, inheriting much of *Neoclassical Synthesis*, is basically build on constraint optimization mathematical models whose applicability in economy has become more and more sophisticated. Having a deterministic character, this strong mathematical theoretic base created the illusion that economics is a *good child of science* having an easy to influence behaviour and being fully controllable. But this *idealistic mask* of economic science is betrayed by its inability to demystify and prevent the appearance in economic systems of destructive phenomena like: *fluctuations*, *market failures*, *depressions*, *disequilibria*, and *crises*, in attempting to meet the theoretical expectations in real world economic systems.

In this paper we propose a new economic model, defined in terms of a *connective structure* composed of elements and connections called *econnectomic*

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model. The model is based on the theory of *complex systems* [1] and introduces a *connective approach* and a *historical dimension* for studying economic systems. Using a revolutionary view, the model can represent various types of economic systems being appropriate to study all aspect of their activity, including the phenomena which tend to disturb it by creating *disequilibria*, thus *raising collapses* and *crises*.

We demonstrate that *unpredictable behaviour* in economic systems can result from small independent shocks generated by the elements inside the system when the system achieves a *dynamical state of self-organized criticality.* No exogenous cataclysmic force is needed to create large catastrophic events. Using proposed model we will analyze the apparition of these phenomena in a simplified distribution network of the form: producers-distributors-consumers. Even this simplistic model based on simple local interactions is plausible to generate complex behaviour.

1. THE MODEL

An economic process can be completely defined by the set of agents which are involved in it and their ability to create connections during economic activity. To denote these things with a single word, we will use term "econnectome", obtained from the term "connectome"- widely used in Neuroscience.

In an econnectome each agent is viewed from two perspectives: (i) as an individual entity having own goals, interests and activities; (ii) as a connected entity which is part of a complex community, is dependent of this community for achieving own goals, and is implied in a global process of the community. Our model is based on the econnectome structure and is called "Econnectomic Model" (ECM). Model structure is defined by $ECM = (A, C, \lambda)$, where:

- A is a fixed set of agents, $A = \{a_1, a_2, ..., a_n\}$, where n represents the number of agents. Agents can have different roles, e.g. producer-consumer;
- C is a dynamical set which represents the connections between agents, $C = \{c_1, c_2, ..., c_i, ...\}$. Each connection links two different agents from the set A. This set is changing during model activity as result of agents tendency to optimize connections, by keeping profitable connections and destroying those that generate losses;
- and λ is an incidence function that associates to each connection $c_i \in C$ an ordered pair of agents $\{u, v\}, u, v \in A, u \neq v$, thus: $\lambda(c_i) = \{u, v\}$ - is a function that connects agent u with agent v by connection c_i.

Participating in an economic process, each agent in the model tracks the profitability (*fitness*) of their connections using function fc. They assign to each connection an individual fitness value which is updated after every interaction between agents supported by the corresponding connection. This fitness function governs the evolution and optimization of the *ECM* structure. Moreover it is a simple but effective mechanism for the implementation of interactional historical dimension in our model, which is a key factor in understanding economy as a continuous complex process.

Additionally each economic agent has a fitness value which shows if the agent is *prepared* to take new connections. These fitness values depend on the agents' activities and form a law of *preferential attachment* in the econnectome which govern the process of apparition of the new connections. The agents with a bigger fitness are more preferred by other agents to connect with.

2. Distribution Network

Using the ECM we will analyze the activity of a producers-distributors-consumers (PDC) distribution network. In the PDC network are involved three types of agents: (*i*) **producers** - the agents who produce economic goods, and generate the supply of economic goods on the market; (*ii*) **distributors** - the agents who connect consumers with producers, distributing economic goods from producers to consumers; (*iii*) **consumers** - the agents who generate the need on the market by requesting economic goods. The connections between consumers, distributors and producers form the distribution chains of the economic goods from producers to consumers. The number of outgoing connections for each agent is limited and relatively small compared with network size.

The preferential attachment that governs the formation of new connections is based on the nodes fitness. In the PDC network the producer's fitness value is the difference between the quantity of *produced* economic goods and the quantity of *distributed* economic goods in current iteration. The distributor's fitness value is the report between the fitness of distributor's sources and the number of agents supplied by these sources minus a penalty for the distance from producers. Consumers does not have a node fitness value, they have just outgoing connections.

3. ECM Activity

The activity of ECM is organized in iterations. In the PDC network, each iteration producers generate a quantity of goods and all consumers or a part of them generate the demand for goods. The goal of ECM is to cover the demand generated by the clients with goods produced by producers, finding and maintaining an effective set of distribution chains.

Having a limited amount of connections, each agent in the econnectome should maintain profitable connections and destroy unprofitable ones evaluating them using connections' fitness function. When the PDC network is generated, a constant fitness value k is assigned to each connection. During model activity, the fitness of each connection in PDC network evolves:

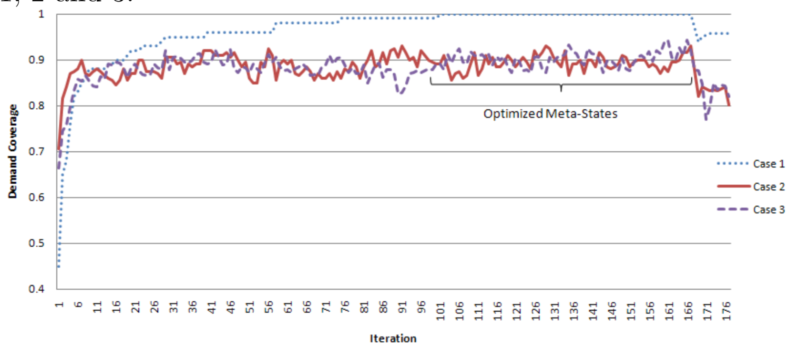
$fc(c_i, i) = fc(c_i, i-1) + (q_p/q_r - 1)$, where i represents iteration number, q_p represents the quantity of goods provided by this connection, and q_r is the quantity of goods this connection should provide.

At the end of iteration the agents remove connections with a minimal fitness and create new connections to replace the removed ones. Initially distribution network is generated randomly, and obviously forms an *ineffective* set of distribution chains. But letting model to evolve some iterations, the distribution chains are gradually improved to a level where consumer demand is *nearly fully* covered and no further improvement is possible. Such configuration of the econnectome is called an *optimized meta-state*. In most cases, the demand coverage is close to optimum but not reaches it, excluding specific cases. Thus, the econnectome evolves close to an optimum configuration but reaches it in very specific cases. This situations is not new to economy, there are many economic processes which meets this situation, e.g. unemployment rate in labour market.

We call this level of network evolution *optimized meta-state*, because it is not a stationary configuration. It is rather a continuous chain of states or configurations which changes network structure but at the same time preserves its ability to nearly fully cover client demand. Each configuration in this chain is close to optimum and is called optimized configuration. Analyzing network evolution, an important property of the model stands out: the local interactions between the agents engage the system in a complex process of learning and adaptation. Moreover, the agents interactions generates a tendency of the model to self organize (see [2] and [3]) the network globally and to maintain optimized meta-state at a close to optimum level. By self-organization we mean that the system naturally evolves to the optimized meta-state without detailed specification of the initial conditions.

This behaviour is very similar to the *emergence of complex behaviour* observed in the models which analyze the sandpile formation, apparition of earthquakes, organization of traffic flow, etc. Our model alongside with all the enumerated models evolves in a state of *self-organized criticality* [4], which in ECM is not a stationary state but is an *optimized meta-state*. These *critical* states behave as an attractor of the system dynamics, and can be viewed as a *complement of the chaos concept*. However, reaching certain levels of critical configuration and interconnectivity, the interdependences between system elements also makes the system very susceptible to small variations or shocks. At the same time, the system cannot be too sensitive since the current state is the result of a long chain of optimization and evolution. The presence of this balanced configuration is considered an important part of the "critical" systems. As result, small variations in the system environment may destabilize these *critical* states which in turn will give rise to unpredictable behaviour in the whole system behaving as a source for apparition of avalanches and catastrophes which easily can be distributed by the connective structure creating

FIGURE 1. PDC network demand coverage dynamics in cases 1, 2 and 3.



domino effects. In the next section we shall see that this qualitative concept of criticality can be put on a firm numerical basis.

4. Numerical Experiments

We will analyze the behaviour of the ECM modelling PDC network in different situations. The PDC network involves 100 producers, 300 distributors and 100 consumers (for first 2 cases). First we let the econnectome to evolve to an optimized meta-state, then small shocks inside the system are consecutively generated, by slightly increasing the demand of a small number of consumers beyond the predefined bounds. We have following 3 situations: **Case 1 and 2** - network has a uniform distribution of connections; production capacity is 2, consumer demand is 2. Each distributor or consumer has one outgoing connection for case 1, and 1-2 connections for case 2. **Case 3** - network has a power law distribution of connections, depending on production capacities. The producers' production capacities are approximately: 56% - 2 units, 20% - 4 units, 11% - 6 units, 7% - 8 units and 5% - 10 units. Consumer demand is 2 units, number of consumers is 173. Each distributor or consumer has 1-2 outgoing connections.

The dynamics of demand coverage in PDC network for these situations is presented in Fig. 1. In each case small shocks are generated at iteration 168, by increasing the demand of 5% of consumers from 2 to 5, consecutively for 10 iterations. The figure shows that the effects of small shocks in these cases are different and they are more destructive when the network has a power law distribution of nodes or when nodes have 1-2 outgoing connections.

Conclusions

The economic science clearly should include a dedicated chapter for studying crises and their rehabilitation. In this paper we analyzed this complex phenomenon using a holistic approach, based on the theory of complex systems and a connective structure called econnectome. Using a simplistic producers-distributors-consumers distribution network, we addressed such complex aspects of economic processes as adaptability, emergence, and self-organization.

The connective approach used to model a universal structure for economic processes provides a rich scientific background for understanding the propagation of destabilization and apparition of the domino effect in the economic systems. The theory and computational approaches of complex systems, offers a new perspective of understanding and modelling the economic processes. Treating economic equilibrium as a continuous dynamical process opens new views for understanding its stability and the potential destructive factors.

We identified that when the system enters an optimized meta-state, small variations inside or outside the economic systems can be the cause of unpredictable behaviour, which further can lead to a global crisis which cover whole systems. The role of self-organized criticality is crucial in economic systems and should be considered as a cause and as a start point of many important economic phenomena.

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