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Entangled economy: An ecosystems approach to modeling systemic level dynamics

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ABSTRACT

We present a model of an economy inspired by individual based model approaches in evolutionary ecology. We demonstrate that evolutionary dynamics in a space of companies interconnected through a correlated interaction matrix produces time dependencies of the total size of the economy, total number of companies, companies' age and capital distribution that compares well with statistics for the USA. We discuss the relevance of our modeling framework to policy making.

1. Introduction

Economies are highly complex systems. History suggests that the standard analysis of an economy with the reductionist approach of individual rationality and utility or profit maximization misses important features about aggregate dynamics and global stability that result from the interactions of economical agents [1]. Complexity theory offers an interesting alternative that has potential to provide better insights about the systemic risks by analyzing the properties of the economy as a whole [2].

In this paper we develop and explore a simple model of an economy inspired by complexity models of evolutionary ecology, in particular the work by Laird and Jensen [3,4]. This kind of analysis is relatively new in the economics literature, especially when it comes to policy design. In a world increasingly globalized with greater interdependence of the individual economies, analyzing systemic risks becomes critical in order to control and avoid global crisis. Andrew G Haldane, Executive Director of the Financial Stability department of the Bank of England, has published numerous papers about systemic risk of the financial sector in which he discusses interesting and innovative ideas for policy design [5,6]. Many of his arguments are based on complexity models of the global banking system where system parameters, such as the density of interbank loans, have a drastic effect on the systemic risk. In general these complexity models consist of units interacting and forming networks. Important tendencies of the systemic risk can be drawn from properties of the network and the dynamics of the system such as the number of links or hierarchy of the network. Such properties could be taken into account when designing economic policies and regulations. The first step to this aim is to establish a minimal modeling framework of the economy that allows us to reproduce, at least at a qualitative level, dynamical behavior consistent with real statistics, and that can be used to develop an appropriate concrete ecological approach to economics allowing us to rely less on purely biological analogies [7,8].

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We have modified the Tangled Nature model of evolutionary ecology developed by one of the authors and his collaborators (see, e.g., Jensen and Arcaute [9] and references therein). The reason we take our outset in the Tangled Nature framework is that it was demonstrated for the case of evolutionary ecology that this very minimalist approach compares very well with observation. From the simple assumption of mutation prone reproduction of individuals whose reproduction rate depends on the instantaneous configuration in type space, a long list of evolutionary and ecological phenomenology is reproduced, for example, the intermittency of extinction and creation events termed Punctuated Equilibrium by Gouold and Eldredge [10], realistic species abundance distributions and species area laws. The model can also reproduce relationships between strength of interaction and diversity seen in microbial experiments [11]. This efficiency in obtaining systemic level phenomenology from some basic dynamical assumptions suggests to us that it is worthwhile to explore to what extent a similar framework can be developed for economics.

Since the foundation of the Santa Fe Institute almost three decades ago, researchers have explored the application of complexity science to approach economic problems avoiding the assumption that an economy is a system in equilibrium [1]. For a complete listing of research in complexity economics, see Kling [12] and the references therein. Our contribution to this literature is to describe an evolutionary model of interacting components representing companies' interactions which aggregate into a model economy that agrees qualitatively with the evolution of the US economy since the great depression, a historical event in time defined by Kling [12] as a restructuring in the world economy that induced a new phase with a new economic structure, which we consider comparable with the beginning of our simulated economy. We find qualitative resemblance in the evolution of the Gross Domestic Product (GDP), the evolution of the number of companies in the economy, and the distribution of company ages and capital. In addition, key parameters of the model that can be related to competition laws and the density of company business interactions and leverage have important effects on the systemic risk of the simulated economy. We suggest that in the future our modeling approach may help to complement the standard equilibrium theory in macro economics by complexity economics.

The remainder of this paper is organized as follows. Section 2 presents the model dynamics. In Section 3, we compare the behavior of our model to the US economy from 1929 to 2010. Section 4 presents preliminary predictions from the model regarding systemic risks of the economy with potential policy implications. Section 5 contains a brief discussion and concludes.

2. The model framework

We use a generalization of the version of the Tangled Nature framework described in Ref. [3]. We take care to include correlations between companies of similar type, say similar production. This does make interactions between companies more complicated, since we cannot just assign interaction strengths at random, but must, as we explain, make sure that the web of interactions between companies possesses the appropriate correlations. A company α is represented by a string of L traits $T^\alpha = (T_1^\alpha, \dots, T_L^\alpha)$ in what we denote the *economy space*, and has capital $C^\alpha(t)$ at time t. Here we have used $T_i^\alpha \in \{0, 1, 2, \dots, 999\}$ with periodic boundary conditions, i.e. there is only one unit distance between 999 and 0. For computational and representational ease in this paper we have set $L = 3$. We can, for example, think of the three coordinates as indicative of the intensity in the use of inputs from the agricultural, industry, and services sectors which are embedded in final product of the company. Hence two companies close together in the economy space will produce similar products which, in terms of the model dynamics, means two companies close together in the economy space interact similarly with any third company, i.e., same kind of business with the same kind of companies, so that for example all car companies are embedded in a similar supply chain. Let us clarify that, since the coordinates are periodical, in this interpretation we need to consider the axis of coordinates as a circle and we can, say, think of the companies at the "top of the circle" (e.g. with $T_i^\alpha \approx 500$) as producing a product highly specialized on the given sector. For example, an automobile company could be high on the industry coordinate circle, at medium height on the services coordinate circle (e.g. it may have a financing department which lends to buyers, as well as publicity and others services involved), and low on the agriculture coordinate circle (e.g. they may use some wood in their cars). And for instance, say, a computing company will be high on the industry circle but it may be on the opposite side of the circle to the automobile company, e.g. the International Space Station can be at the very top of the industry circle with coordinate 500, a car company can be a little lower at coordinate 550, and a computing company can be 450. There are 1000^3 possible companies in the considered economy space. Clearly not all companies are interacting with all other companies. We therefore use a sparse $1000^3 \times 1000^3$ interaction matrix to represent the interactions between companies. We describe below and in the Appendix how we construct this interaction matrix in order to represent companies' interdependence in a sensible qualitative manner.

We use a stochastic sequential update for the capital $C^\alpha(t)$ of company α at period $t + 1$ by following the update algorithm described below. One *iteration* corresponds to $N(t)$ stochastic updates, where $N(t)$ is the number of companies present at time t. The companies affect each other in two different ways: one is doing direct 'business', which we will call interactions, representing anything from buying or selling merchandise between them, to consulting and engaging in financial transactions; the other is competition, and it applies to companies that are close together in the economy space (i.e. produce similar products). The outcome of the interactions and competition together with the natural resources available in the system determines the probability of gaining or losing capital at the end of the iteration.

Company α interacts with company β with strength $J(\alpha, \beta)$ independent of the corresponding reciprocal interaction strength for $\beta, J(\beta, \alpha)$. Only a subset of these α–β interactions are active; that is, the interaction matrix $J_{(\alpha,\beta)}$ is sparse. The