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Interaction in agent-based economics: A survey on the network approach

Leonardo Bargigli [a], Gabriele Tedeschi [b,*]

[a] *Quantitative Finance Group, Scuola Normale Superiore, Pisa, Italy*

[b] *Department of Economics, Universitá Politecnica delle Marche, Italy*

HIGHLIGHTS

- We introduce concepts and tools used in economic network models.
- We show the ways in which economic agents interact and consequences of their interaction on the system.
- We show that networks can introduce complex phenomena in economic systems.
- We study the endogenous evolution of networks.

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ABSTRACT

In this paper we aim to introduce the reader to some basic concepts and instruments used in a wide range of economic networks models. In particular, we adopt the theory of random networks as the main tool to describe the relationship between the organization of interaction among individuals within different components of the economy and overall aggregate behavior. The focus is on the ways in which economic agents interact and the possible consequences of their interaction on the system. We show that network models are able to introduce complex phenomena in economic systems by allowing for the endogenous evolution of networks.

1. Introduction

Various approaches may be followed in modeling the connections among agents: from local to global, from deterministic to stochastic, from exogenous to endogenous interactions. Clearly, there does not exist a "best" approach in modeling agents' interaction; instead, the choice of model should depend on the "circumstances" to be modeled and on the purpose of the model [1].

Local interaction characterizes models in which agents' behavior (and then preferences, information, and choices) is directly affected by others' behavior, rather than being mediated by a centralized agent or (market) mechanism. The basic assumption in these models is that individuals interact locally, with a neighbors set determined by a social or economic "distance metric". Instead, when the interaction is *global*, individual behavior depends on the behavior of all other agents (for instance, because there are very low costs of information/transaction and geographical or socioeconomic distance is negligible). The rule defining the set of interacting agents can be of *exogenous* (e.g., a von Neumann or Moore neighborhood in a "lattice" economy) or *endogenous* nature (e.g., an agent decides to interact with a neighbor – and not with another one – because this partner choice maximizes its utility). Moreover, the set of neighbors may be the result of a *deterministic* (again, a von Neumann or Moore neighborhood) or *stochastic* rule (e.g., the switching from a partner to another depends on a probability

* Corresponding author. Tel.: +39 0712207103.
E-mail addresses: leonardo.bargigli@sns.it (L. Bargigli), gabriele.tedeschi@gmail.com, g.tedeschi@univpm.it (G. Tedeschi).

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distribution). All in all, the interactive structure may be *static*, that is the neighbor sets are determined once and for all, or *dynamic*, because it evolves along time depending on model assumptions.

In this paper we list, among the main features of Agent Based Models (ABM), the explicit modeling of interaction space, and in particular the preference towards local interaction as a more realistic modeling device than global interaction, which is generally at odds with bounded rationality. Interaction, in fact, is quoted as one of the main ingredients of ABMs. We are going to push further these claims, by advocating the intimate connection between ABM and network or graph theory.[1] The latter, in fact, provides the basic mathematical concepts needed to describe exactly any collection of interactions between agents, as well as the tools to analyze the collective, emerging, properties of this collection. These properties, on their part, allow us to investigate how interaction patterns affect the behavior of agents. Shortly, we may state that each ABM maps onto one or more networks (since the pattern of interaction between agents could be either fixed or changing over time), and the mathematical properties of these networks can be used to analyze and eventually forecast, at least for some variables, the behavior of the model.[2]

The quest for a deeper connection with network theory has become an important topic in the research agenda of ABM, with a growing amount of research efforts especially devoted to the twin problems of interaction over fixed networks (see Ref. [6]) and of the endogenous network formation (see Ref. [1]). On the other hand, we must admit that currently the two fields are only partially overlapping. For example, the economics-oriented handbook of Jackson [7] makes only a marginal reference to ABM, while the more physics-oriented monograph of Vega-Redondo [8] is silent on the subject. Among the few systematic efforts to better integrate the two approaches, it is worth to mention the ambitious theoretical framework proposed by Potts [9], which is explicitly geared towards the multi-agent simulation modeling, and relies heavily on network theory.

In general, it is clear that Walrasian economics requires a complete network, where any agent (firm or consumer) exchanges information with all other agents simultaneously and instantaneously at no cost. It is also clear that this network cancels out from the beginning the possibility of heterogeneous information sets among agents. Moreover, agents have access to the same set of decision rules (i.e., again, the network between agents and decision rules is a complete one), which are on their part evaluated with respect to the same objective function. Finally, all sources of heterogeneity are lost and the representative agent is obtained. AB economics requires instead, as key notion at the level of agents, that of neighborhood, which may be framed either in a deterministic (fixed set) or in a stochastic (fixed probabilities) flavor, as well as with reference to search costs or any other suitable matching heuristic. The difference with Walrasian economics becomes substantial, as soon as the asymmetry between agents is introduced with the help of heterogeneous neighborhoods, since in that case the coexistence of different classes of agents is, at least in principle, allowed.

At the system level, instead, the key notion of AB economics, in this context, is that of structure. Each non trivial pattern of connections between agents can be viewed as a structure, which may act as a constraint over the path followed by the system as a whole (in fact, the same set of decision rules acting on structurally different neighborhood will generally produce different values of the state variables), and/or emerge as a by-product of decision rules themselves, whenever these include algorithms for partner selection and matching.

From the point of view of network theory, each relevant structure is associated with a set of observables. In general, it would be difficult, and possibly useless, to predict the value of observables at the single agent level (when a definition at this level is possible). That is why network theory strongly relies on a statistical approach, whereby we are more interested in characterizing the statistical properties (e.g. moments or probability distributions) of observables, viewed as random variables, across the population of agents. Network theory is interested in (some of) the mesoscopic properties of systems, and this meso-level of analysis is a natural one to define the structure. In fact, the latter is obviously a meso concept, since it entails the description of a system by means of its main components and their relationships. As we will see, network theory describes the main components of interaction (defined by observables) along with their relationships, since the statistical properties of one observable are in general not independent from the statistical properties of other observables.

To summarize, network theory deals with the structure of interaction within a given multi-agent system. Consequently, it is naturally interested in the statistical equilibrium of these systems, to be defined as the stability of probability distributions of observables, which implies "a state of macroscopic equilibrium maintained by a large number of transition in opposite directions" [10]. Following this path, we come close to the idea, championed by Aoki [11], of reconstructing macroeconomics under the theoretical framework of statistical physics and combinatorial stochastic processes. Not surprisingly, the same methods (which were originally developed to study systems made of large numbers of interacting micro-units by means of a set of macro state variables) are now of fundamental importance in the field of network theory and, for the same reasons, they are expected to take an increasing role in ABM.

The paper is organized as follows. In Section 2, we introduce some basic notions of network theory. In Section 3 we focus on the issue of interaction over fixed networks, by introducing two well known topologies: Poisson networks and

[1] In this paper we are going to use "graph" and "network" as equivalent terms, although it could be possible, in principle, to separate the more mathematically oriented tradition of graph theory (see e.g. Ref. [2] or [3]) from the more physics-oriented tradition of network theory (see Refs. [4,5]).

[2] However, many contributions in the field of AB modeling, as well as in other fields of economics, do not explicitly make use of network concepts and measures. Ref. [1] contains a very useful discussion on the various approaches followed in AB economic models, with a particular focus on the endogenous interaction.