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Does Network Theory Connect to the Rest of Us? A Review of Matthew O. Jackson's *Social and Economic Networks*

James E. Rauch*

The ubiquity of networks in our social lives has long been recognized, and their importance in our economic lives is increasingly recognized as well. Yet the literature synthesized in Matthew O. Jackson's Social and Economic Networks, *which covers the theory of how networks form, decay, and shape behavior at a general level, has had little influence on either applied theory or empirical work in this area. This is partly because of limitations of network theory as it has evolved in this literature. After describing the network theory presented in the book, I discuss these limitations and make some tentative suggestions as to how they might be overcome.* (*JEL* D85, L14, Z13)

1. *Introduction*

The ubiquity of networks in our social lives has long been recognized. Their importance in our economic lives is increasingly recognized as well in areas as diverse as labor markets (Kaivan Munshi 2003), international trade (James E. Rauch 2001), industrial organization (Rachel E. Kranton and Deborah F. Minehart 2001), and economic development (Oriana Bandiera and Imran Rasul 2006). Hence, the market appears ripe for *Social and Economic Networks* (Princeton University Press 2008)—the most ambitious economics textbook on the subject to date.[1] Yet the literature synthesized in this book, which covers the theory of how networks form, decay, and shape behavior at a general level, has had little influence on either applied theory or empirical work in this area. This is partly because, until recently, network analysis at this level was ceded to sociology. But, as I shall argue in this review, it is also the result of limitations of network theory as it has evolved in this literature. In section 3, I will describe these limitations and make

* Rauch: University of California, San Diego, and the National Bureau of Economic Research. I thank Nageeb Ali for helpful discussions and the editor for valuable comments.

[1] I am aware of two previous volumes covering similar material that could be called textbooks, Sanjeev Goyal (2007) and Fernando Vega-Redondo (2007). Jackson's book is more than 50 percent longer than either and contains exercises for each chapter.

some tentative suggestions as to how they might be overcome. First I will describe the network theory presented in the book.

2. Summary of the Book

Social and Economic Networks is a graduate level textbook. It is definitely not for someone who wants a casual introduction to the subject. The comprehensive list of 675 references alone is worth the modest $65 purchase price. For the prospective buyer who has an opportunity to browse the book, I recommend reading the first, overview chapter, which gives an excellent feel for what is to come. In this section, I will briefly review the other chapters and highlight what I believe is of greatest interest to economists who are not network theorists. I will not discuss the last three chapters, which cover "advanced" topics, although I will refer to material in chapter 13 in the next section of this review.

Following the introductory chapter, chapter 2 defines terms used to describe properties of networks**.** Here I will paraphrase several definitions that will be useful in the discussion below. The bulk of the networks studied in the book, and the only networks I will consider in this review, are *undirected* and *unweighted graphs*: a set of *nodes* between any two of which there exists or does not exist a *link*, each of which is reciprocal (if you know me I also know you). The nodes are agents in most economic applications. A *complete network* is one in which every node is linked to every other node, as in a stereotypical small town. The *degree* of a node is the number of links that involve that node, and is a natural measure of the node's popularity. The *distance* between two nodes is the number of links in the shortest *path* between them, commonly known as degrees of separation. Networks can be partitioned into *components* such that two nodes are in the same component if and only if there exists a path between them. If there is a path between every pair of nodes, the network consists of only one component. Finally, *clustering* refers to the tendency for two nodes that are linked to a third node to also be linked to each other: two people who know me are more likely to know each other than are two randomly selected people.

Chapters 4 and 5 present models of random network formation, a major goal of which is to explain the stylized facts of large networks presented in chapter 3. A good example of a large network is the network of coauthor relationships among all economists. In describing the stylized facts of such networks, it is useful to have a standard of comparison. A common baseline is a random network in which one fixes a set of n nodes and forms links independently with probability p. For large n and small p, the distribution of the number of degrees per node is approximately Poisson. Relative to this Poisson baseline, a typical large network has more nodes with very high degree and more with very low degree ("fat tails"). The average distance between nodes in observed large social networks is surprisingly small, measured against the Poisson baseline or naive intuition. This is the famous "small world" phenomenon. A third key stylized fact is very high clustering relative to random networks.

Measured against these stylized facts, models of random network formation have been most successful in explaining fat-tailed degree distributions. Researchers have been able to obtain Pareto degree distributions by allowing the number of nodes to grow over time and assuming that new nodes link to existing nodes in proportion to their degrees, a "rich get richer" process similar to the processes believed to be generating Pareto distributions for city sizes, wealth, and other variables. Actual degree distributions tend to lie in between the Pareto and the Poisson and can therefore be explained by "hybrid models" in which new nodes link to existing nodes both uniformly at random and in proportion to their degrees, with the split between the two processes determined by a parameter that can be estimated.

Short average distance between nodes and high clustering can actually be explained with much less difficulty by models in which links between nodes are formed by choice rather than at random, which brings us to chapter 6. Now the nodes are agents who consider costs and benefits when forming links. In the model of section 6.5, agents are equally divided between "islands." The cost of forming a link is lower within an island than across islands. Not surprisingly, this model gives rise to high clustering and, in fact, each island becomes a complete network. But this high clustering generates a high value of forming links between islands because the linked agents gain indirect access to many other agents. A few such links form, which is enough to yield a short average distance. These results illustrate the value of imposing some exogenous structure on the network formation process, a point on which I will expand below. I will also return to the process of link formation and decay that is discussed in chapter 6.

Whether links are added and subtracted at random or purposefully, it is assumed throughout chapters 4–6 that the process is decentralized rather than coordinated. The reader is left to judge whether this assumption is appropriate.[2] The efficiency of networks formed without coordination is a subject on which Jackson touches at several points in his book but it is not a major focus and I will mention it only in passing in the next section of this review.

Describing and understanding the properties of networks has long been a core pursuit in sociology but is of interest to few economists. Most economists are more interested in the way network structures might affect socioeconomic outcomes than in the network structures themselves. This is the subject of chapters 7 through 10.

The importance of network structure for diffusion of diseases or information is self-evident and has engendered a substantial literature in epidemiology and marketing. Jackson surveys this literature in chapter 7 and analyzes how differences in network structure yield differences in steady-state infection rates. Chapter 8 shows how network structure can transmit social influence and shape opinion formation. Chapter 9 considers more active and complex behavior on the part of agents (nodes) and brings in the tools of game theory to predict their decisions and the equilibria of the networked societies to which they belong. In chapter 10, Jackson shows how network structure can influence outcomes at the heart of mainstream economics such as unemployment. I will discuss this application in more detail below.

Network structure is taken as given throughout chapters 7–10. Some use is made of the random network formation models of chapters 4–5 in motivating the features of the network structures assumed, but the choice-based framework for network formation presented in chapter 6 is completely absent. In the chapter on diffusion, Jackson recognizes the possibility that allowing network structure to be influenced by choice could undermine the validity of the results he presents. He writes, "Perhaps the most important aspect that is neglected in the above analyses is that the networks often actively react to the ongoing process. For example, in the

[2] For example, one reader might think an intrafirm network, in which the nodes are employees, is coordinated, whereas an interfirm network, in which the nodes are firms, is not. Another reader might argue that even the intrafirm network is formed without coordination, through interactions at the proverbial water cooler, and a third reader might argue that even the interfirm network is coordinated, by the developer of an industrial park or the lead firm in a business group.

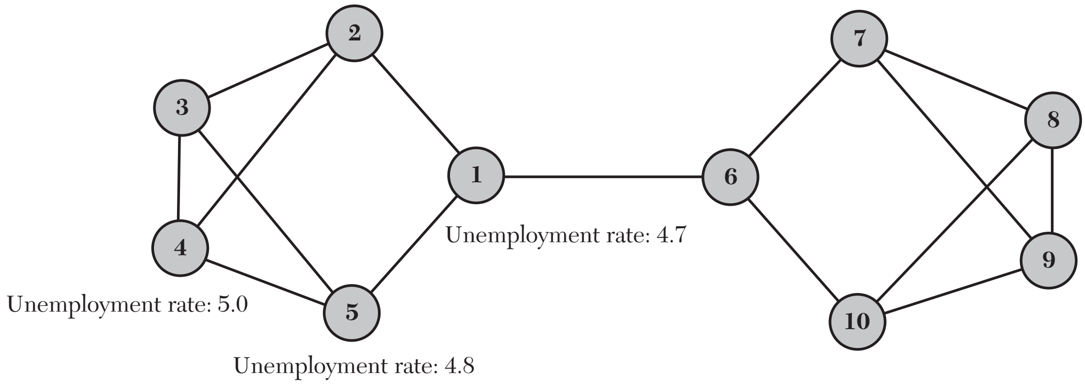

Figure 1. Unemployment Rates as a Function of Position in a Network

Source: Jackson, *Social and Economic Networks*, p. 345, figure 10.4.

case of a serious disease outbreak, some individuals react by seeking immunizations and/or avoiding contact with infected individuals" (p. 208). The absence of a role for choice in network formation becomes more glaring when the analysis moves from the impact of overall network structure on aggregate variables to the impact of micro network structure on individual outcomes. I believe that, for most economists, the latter holds the greatest promise as well as the greatest pitfalls for application of network theory. It is the main subject of the next section of this review.

3. *Using Network Theory*

In section 10.2.2, Jackson describes a model of employment in which workers can learn of job openings directly or from other workers to whom they are linked directly. A worker learning of a job will accept it if he is unemployed and pass the knowledge of the job opening to any unemployed network "neighbor" with equal probability otherwise. (If all his network neighbors are employed, the knowledge of the job opening is lost.) The model predicts correlation in neighbors' employment status, as would a typical "social interactions" model (Giorgio Topa 2001). Jackson also shows, however, that more detailed knowledge of network structure can lead to more detailed predictions regarding employment. An obvious prediction is that the employment probability of a worker increases with his degree (the number of workers to whom he is directly linked). A more interesting prediction is illustrated by figure 1 (figure 10.4 in the book). All workers in the figure have degree 3, yet workers 1 and 6 have lower unemployment probabilities than the rest. Note that 1 and 6 are not part of any cluster: none of their neighbors is linked to each other. It follows that the employment outcomes of the neighbors of 1 and 6 are less correlated than the employment outcomes of the neighbors of the other workers. In turn, it is less likely that their neighbors are all unemployed and pass on no information or all employed and pass on redundant information.

In the language of Ronald S. Burt (1992), workers 1 and 6 bridge a "structural hole" in the network of figure 1. Jackson's prediction that they are more likely to be employed is consistent with empirical findings from economic sociology that agents with bridge links perform better than agents with cluster links (see Burt 2000 for a survey): firms that bridge clusters in interfirm networks show higher profits, managers that bridge clusters in intrafirm networks receive higher pay and more rapid promotions.

At a theoretical level, analysis of the type illustrated in figure 1 is a clear advance over standard "peer group effects" models. In these models, agents are divided into disjoint groups. The impact on any agent of his group is a function of the equally weighted average characteristics of all agents in the group (Vernon Henderson, Peter Mieszkowski, and Yvon Sauvageau 1978; George J. Borjas 1992). The implicit network structure is that each group forms a separate component that is complete, so that within any group every agent is in a symmetric position and is connected to every other agent in the group, but there are no links across groups. This is a very restrictive and not very realistic network structure. Behind it is an implicit theory of network formation that sociologists call *homophily*, meaning the tendency for like to link to like.

When it comes to empirical applications, however, the peer group effects approach to modeling network effects on agent performance has two important advantages. First, if there are n agents and k characteristics, one only needs to collect nk items of data. The presence or absence of each of the $n(n-1)/2$ potential network links is simply assumed. Second, membership in a group is typically *ascriptive* (one is born into it) or otherwise plausibly exogenous. [3] In contrast, most economists are unwilling to accept the exogeneity of an agent's position within a given network structure, even if they were willing to accept the exogeneity of the structure itself. In figure 1, agents 1 and 6 may have the lowest unemployment not because of their network positions but because they were the most aggressive or talented in pursuing access to nonredundant information. In other words, use of network position to explain performance is confounded by the classic problem of selection on unobservable characteristics. Contrary to what Jackson suggests in section 13.1, then, knowledge of micro network structure does not offer a way around the well-known econometric difficulties of estimating peer group effects and other social influence models (Charles F. Manski 1993), at least not without making use of still further information.[4] Absent a remedy for the selection problem, use of micro network structure (network position) to predict economic outcomes for agents is unlikely to gain popularity.

If panel data are available, one can of course try to control for the relevant unobservable characteristics using agent fixed effects or lagged endogenous variables. The econometrically preferred remedy is to instrument for network position. This latter approach has the potential to change the problem that endogeneity presents for application of network theory into an opportunity. If we can identify some exogenous past pattern of connections, then, in principle, we can use network theory to predict evolution of the current network from this pattern, thereby establishing one or more valid (possibly nonlinear) instruments. [5]

[3] Ascriptive networks may have interesting micro structure, through extended family relationships for example, but this has rarely been exploited in the economics literature.

[4] See, however, Yann Bramoullé, Habiba Djebbari, and Bernard Fortin (2009). I thank Yannis Ioannides for bringing this work to my attention.

[5] Ideally, we would like theory to tell us how a network evolves from one period to the next as a function of the preceding period's network structure (and memory of past networks, most generally) and agents' individual attributes. In each period (not just period zero), the network would act as a set of constraints that shapes agents' decisions in that period. Because of the theory, we would then be able to say what aspects of those constraints are at least partially independent of the agents' attributes.

With this aim in mind the theory of strategic network formation described by Jackson in chapter 6 could prove to be a helpful starting point. In this chapter, he introduces the key concept of "pairwise stability." A network is pairwise stable if it satisfies two conditions: (1) if a link between two agents is absent then it cannot be that both agents would benefit by adding that link and (2) if a link between two agents is present then it cannot be that either agent would benefit from deleting that link. Jackson shows that efficient networks that maximize the sum of payoffs to all the agents need not be pairwise stable and vice-versa.[6] The reason is that when choosing whether to form or maintain links, an agent in a network does not take into account his impact on relationships between other pairs of agents who are connected indirectly through him.

Pairwise stability is a more realistic approach to network formation than one in which omniscient agents interact in a network formation game. Nevertheless, it still provides too many degrees of freedom for addition and subtraction of network links. Past interactions do not influence current choices. There are no ties of affect or mutual adaptation and learning that make existing links "sticky," hence no "fear of commitment" that impedes formation of new links. A minimal element of a more realistic approach would be to model the costs and consequences of link formation so as to cause links to display hysteresis. Without such a modeling change, there is little hope that an exogenous past pattern of links, should one be identified, would have much influence on future network positions in a changing environment, though any observed pattern of links could persist over time simply because the environment is stable.

[6] Later in chapter 6 and in chapter 11, Jackson considers the possibility of transfers between agents. Not surprisingly, these tend to promote efficiency.

Supposing that network theory were to move in the direction I suggest, from where would the exogenous past networks come? The ascriptive groups of the peer effects literature are an obvious possibility. Rauch and Joel Watson (2007) suggest that plausibly exogenous links could also be created in firms. The assumption is that the combination of bureaucracy and proximity that exist within a firm can establish the requisite exogeneity, though this is by no means a foregone conclusion. The overall network evolves as agents leave their firms to join other firms, new or existing, or to become unemployed. Firms play the role of Jackson's "islands" discussed above, but the difference is that the dense interconnectedness of agents within firms are features of an initial network that shapes future evolution rather than an end result of assumed differential connection costs. The choice of firms would allow researchers interested in the evolution of economic networks to take advantage of the increased availability of matched firm–worker data sets, which allow employees to be tracked from firm to firm.

A less ambitious empirical application of network theory would be to compare performance across networks rather than across agents within a network. Now selection into network position is no longer an issue, though endogeneity of overall network structure may be. Ray E. Reagans, Ezra Zuckerman, and Bill McEvily (2007), for example, examine time to project completion for the project teams of a research and development firm. A network structure exists among the members of each team. Reagans, Zuckerman, and McEvily measure this using the links that existed between team members *prior to formation of the team*, so that any relationship between network structure and time to completion cannot be attributed to addition or subtraction of links during the course of the project.[7] Moreover, each employee of the firm is a member of multiple teams, both simultaneously and serially, so individual fixed effects can be added to the equation explaining time to completion. Network density (essentially the percentage of all possible links between team members that actually exist) is found to reduce time to project completion, in line with theory that predicts that denser networks increase trust and cooperation. This work suggests that panels with multiple, overlapping teams may provide good nonexperimental settings for identifying impacts of network structure on outcomes of interest.

4. *Conclusion*

The intellectual interest of the network theory presented in *Social and Economic Networks* is not in doubt, but its relevance for economists interested in explaining socioeconomic outcomes rather than explaining the properties of networks themselves has not yet been convincingly established. We must recognize that, within economics, this is a young literature in which fundamental issues regarding network formation and evolution remain to be worked out. I nevertheless feel that the potential for this network theory to connect to the rest of us exists and have outlined at least one direction in which the theory could move that would facilitate that connection. There are surely other approaches to achieving this goal. I hope that readers of this review, and of Jackson's book, feel that it is worth trying.

[7] By adopting a strategy of using the prior pattern of links to explain current performance, Reagans, Zuckerman, and McEvily implicitly assume the "stickiness" of network links that I argued above would be a crucial element of any more realistic theory of network formation. Note that the teams studied by Reagans, Zuckerman, and McEvily do not actually constitute disjoint networks because prior links may exist between employees assigned to different teams.

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