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Peer effects in endogenous networks

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ABSTRACT

This paper presents a model of strategic network formation with local complementarities in effort levels and positive local externalities. Results are obtained for a general class of payoff functions, which subsumes the linear-quadratic specification frequently used in theoretical and applied work. We assume homogeneous agents and characterize equilibria for two-sided and one-sided link formation. (Pairwise) Nash equilibrium networks are nested split graphs, which are a strict subset of core-periphery networks. We highlight the relevance of the convexity of the value function for obtaining these structures. More central agents are shown to exert more effort and obtain higher gross payoffs in equilibrium. However, net of linking cost, central agents may obtain strictly lower net payoffs. The curvature of the value function is also important for efficiency considerations. These findings are relevant for many social and economic phenomena, such as educational attainment, criminal activity, labor market participation, and R&D expenditures of firms.

1. Introduction

Peer effects and social structure play an important role in determining individual behavior and aggregate outcomes in many social and economic environments. This has been documented by a large body of empirical work, which finds that peer effects and network position are crucial for educational attainment, criminal activity, labor market participation and R&D expenditures of firms. In these settings an agent's optimal action and payoff is thought to depend directly on the action or payoff of others (peer effects), while the relevant reference group is determined by a network of bilateral relationships (social structure). Given the wide set of social and economic situations where peer effects and network structure are important for determining outcomes, we aim to understand why certain structures commonly arise and how these affect payoffs and incentives to exert effort. We therefore endogenize the network in the presence of peer effects, where, in accordance with empirical work, peer effects are assumed to induce positive local externalities and strategic complementarities.[2]

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[2] See Hoxby (2000), Sacerdote (2001), Glaeser et al. (1996) and Case and Katz (1991) for educational attainment, Ludwig et al. (2001), Bayer et al. (2009) and Damm and Dustmann (2014) for crime and juvenile delinquency, Topa (2001) and Conley and Topa (2002) for labor market participation and Cohen and Levinthal (1989, 1990) and Levin and Reiss (1988) for R&D expenditures.

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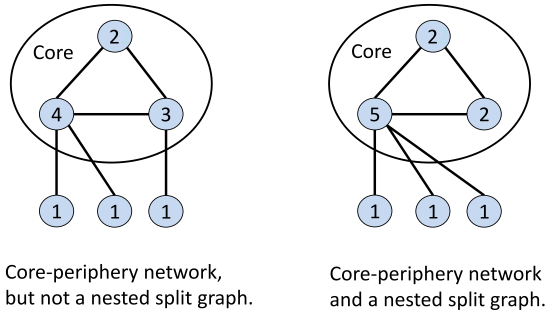

Fig. 1. Core-periphery networks and nested split graphs.

The interpretation of a connection and an agent's effort level will depend on the particular application one has in mind. When considering bilateral R&D partnerships among firms, for example, then a R&D partnership can be thought of as a link in a network, while a firm's production level may be thought of as effort. Assuming that a firm's marginal production cost is decreasing in the production level of its R&D partners (e.g. due to spillovers from learning-by-doing), then production/effort levels of directly connected firms can be shown to display strategic complements and to induce positive externalities. We formally derive the commonly used linear-quadratic payoff specification for such an application in the next section. In contrast, in the case of crime, social interaction is considered to be an important channel facilitating individual criminal behavior. In this context a link is taken to be the social tie between two individuals, while an agent's criminal activity is interpreted as effort.[3]

Our simple model captures frequently observed patterns regarding effort levels, performance and network structure. Due to the reinforcing interplay between linking decisions and incentives to exert effort, ex-ante identical agents may obtain different ex-post outcomes. More central agents display higher effort levels and higher gross payoffs. This is much in line with the empirical literature.[4] Perhaps surprisingly, however, more central agents may obtain strictly lower net payoffs (net of linking cost) in equilibrium. This is informative for empirical work, which generally disregards linking cost. Equilibrium networks are shown to be nested split graphs, which are a special case of core-periphery networks. Core-periphery structures are often observed in empirical studies and empirical support for nested split graphs has also been established in environments where peer effects and social structure are important.[5,6] Note that, while nested split graphs are well known in the mathematical graph theory literature, these networks have only been identified recently in economics.[7]

We illustrate the difference between core-periphery and nested split graphs in Fig. 1, while formal definitions are provided in the Analysis section. In a core-periphery network the set of agents can be partitioned into two sets, called the core and the periphery, such that all agents in the core are connected to each other, while no pair of agents in the periphery is connected (Bramoullé, 2007). In a nested split graph the neighborhood of every agent is contained in the neighborhood of agents with a higher number of links.

The setup of our model is simple. Agents simultaneously choose a non-negative, continuous effort level and create links at a cost. The significance of a link is that direct neighbors in the network "access" or benefit from each other's effort levels (positive local externalities) and an agent's incentive to exert effort is increasing in the sum of direct neighbors' effort levels (strategic complementarities). We assume payoff functions such that best response functions are either linear or, different from much of the prevailing literature, concave. Furthermore, the corresponding value function is assumed to be convex. That is, when best responding, own payoffs are convex in the sum of effort levels of direct neighbors. The economic interpretation of a convex value function is simple in our context. An agent's incentives to create links to other agents, thereby benefiting from their exerted effort, are increasing in the effort level of agents to whom a connection is already established. We will show that this is what drives most of our results and, more specifically, provides a rationalization for the frequently observed core-periphery networks and nested split graphs. Note that a convex value function is consistent with payoff functions that are concave in the sum of neighbors' effort levels (i.e. diminishing marginal returns) and may be interpreted as a strong form of strategic complementarity. Note further that in all the applications considered above, link formation is typically thought to be two-sided. This motivates the use of pairwise Nash equilibrium as our notion of strategic stability, since it reflects the bilateral nature of creating a link (and paying its cost).[8] To the best of my knowledge our paper is the first to solve a two-sided network formation model in this context.

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[3] For additional motivation, applications and derivations of the linear-quadratic payoff specification see König et al. (2014).

[4] See Baldwin et al. (1997), Lin (2001), Powell et al. (1999) and Ahuja (2000).

[5] See Adamic and Adam (2003), Canter (2004), Powell et al. (1999) and Baker et al. (2004).

[6] See Åkerman and Larsson (2014), Uzzi (1996) and Soramaki et al. (2007). König et al. (2014) provide a discussion of nested split graphs with further references, empirical evidence and an interpretation of the theoretical model in terms of networks of banks and trade networks.

[7] Goyal and Joshi (2003) is a very early paper that features nested split graphs (the authors call them interlinked stars).

[8] Pairwise Nash equilibrium was first discussed in Jackson and Wolinsky (1996). For applications see, for example, Goyal and Joshi (2003) and Belleflamme and Bloch (2004).