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Collaboration in networks with randomly chosen agents☆

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ABSTRACT

The present paper considers a finite population of agents located in an arbitrary, fixed network. In each period, a small proportion of agents are randomly chosen to play a minimum effort game. They learn from both their own and their neighbors' experiences and imitate the most successful choices, though they may occasionally make mistakes. We show that in the long run all agents will choose the highest effort level provided that each agent's neighborhood is large.

1. Introduction

Interaction within networks is an active research field for economists (for an overview, see Goyal, 2011; Özgür, 2011). The literature usually explores local interaction, where individuals only interact with their direct neighbors. Nevertheless, in a wide range of economic and social situations, individuals interact with strangers and interaction between the same group of individuals occurs with low frequency. Examples of this include peer-to-peer file sharing and online anonymous financial transaction services. It is quite common that each time only a small proportion of all agents take part in the interaction. In order to capture these phenomena, the present paper assumes that in each period, a fixed number of agents are randomly chosen from a finite population to interact and that these selected agents make their choices based on their own and their neighbors' experiences.

More specifically, let us concentrate on the example of peer-to-peer file sharing. Typically, a large file is broken down into much smaller chunks. These chunks can be obtained from multiple peers by each peer uploading the downloaded chunks

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to others. Each peer is able to determine his own uploading speed. The higher the uploading speed, the more bandwidth is occupied; then, the more the peer has to pay. Typically, how quickly file sharing occurs is determined by the slowest speed.

Hence, we consider a finite population of agents located in an arbitrary, fixed network. In each period, a fixed number of individuals from the whole population are randomly chosen to play a minimum effort game. Players choose among different effort levels and their payoffs depend on the minimum effort chosen by all players. Minimum effort games model situations where the performance of a group is determined by the lowest effort individual member.[1] Each selected agent is assumed to observe the effort levels and payoffs of his neighbors and himself, in the most recent interaction and to imitate the most successful choice. Occasionally, agents make mistakes when revising their choices.

We find that if each agent has a large number of neighbors, in the long run all agents will choose the highest effort level and the socially optimal outcome will obtain provided that the probability of random noise is sufficiently small.[2] In the language of economic and social networks, highly cohesive networks can lead to the socially optimal outcome.[3] We also show that when one agent does not have enough neighbors, in the long run all agents will exert the lowest effort level and only the socially worst outcome occurs.

The intuition underlying the main results is as follows. For simplicity, consider a connected observation network. If, in a given period, all selected agents exert the highest effort level, they will receive the maximal possible payoff. With positive probability, in the next period, their neighbors are selected and owing to the imitation rule will choose the highest effort level. Following this logic, the highest effort level can spread to the whole population. Now consider the reverse transition. First, assume that some player has strictly less neighbors than participants in the minimum effort game. If this agent and all of his neighbors are selected to play the minimum effort game and he makes a mistake and switches to the lowest effort level then this seed agent will earn the highest payoff. Following this interaction, assume that the seed agent is chosen again and interacts only with agents who are not neighbors. These new interaction partners will now earn a payoff that is no larger than the payoff of the seed agent. By consecutively selecting the appropriate interaction partners the payoffs of all agents can be lowered below the payoff of the seed agent. From this point onwards, the seed agent's neighbors will copy the lowest effort level with certainty. One can extend this argument to the case where the size of the neighborhood of the seed agent is larger than the number of participants in the minimum effort game. Doing so, one has to first make sure that none of the seed agent's neighbors earns a payoff higher than the seed agent (which would make him switch back immediately). Naturally, the larger the size of the smallest neighborhood the more mistakes will this take. For the transition mechanisms above, it is relative size rather than the identity of the highest or lowest effort level that matters. In most cases, there are only two candidates for stochastically stable equilibria: socially optimal and worst outcomes; the minimum degree decides which of these will emerge.

Our work contributes to research on local interaction. Starting with the seminal papers of Blume (1993, 1995) and Ellison (1993), much of the literature is concerned with local interaction games. It is assumed that agents are located in a fixed network and interact with their direct neighbors (Alós-Ferrer and Weidenholzer, 2007, 2008, 2014; Boyer and Jonard, 2014; Cui, 2014; Ellison, 2000; Eshel et al., 1998; Morris, 2000). Two prominent dynamic adjustment rules are used in these models: myopic best-response reply and imitation (for an overview, see Weidenholzer, 2010). As a complement, the present paper takes into account the possibility that individuals may interact with strangers and analyzes the long-run behavior of imitation dynamics.

Our paper also relates to research that explores the effect of random matching on learning dynamics in games. Building on Kandori et al. (1993), Robson and Vega-Redondo (1996) show that for a coordination game, a random pairing-up mechanism can lead to the emergence of the Pareto efficient rather than risk dominant equilibrium. And, given that agents are located in regular networks, Anderlini and Ianni (1996) introduce the concept of 1-factor which enables each agent to be coupled with one neighbor and show that in the long run different actions of a coordination game may survive at different locations. Although opponents may change over time, these papers assume that in each period, each individual plays a 2×2 coordination game with someone else. In contrast to these papers, the present paper assumes that in each period, only a small proportion of agents are selected to play a minimum effort game.

One closely related paper is that of Khan (2014) who proposes a model of global random interaction and local observation on a fixed network. Khan (2014) assumes that in each period all individuals are randomly partitioned into pairs to play a 2×2 coordination game and update their choices by imitating their most successful neighbors. Khan (2014) shows that the Pareto efficient convention is always stochastically stable and offers sufficient conditions for this outcome to be a unique stochastically stable equilibrium. Besides the difference in the base game, the present paper differs from Khan (2014) by assuming that in each period, only a small fraction of individuals interact rather than the whole population. Owing to rare and random interaction, the lowest effort level can spread from one agent and neighbors to the whole population even without any further mutation provided that the observation network is connected. Therefore, the socially optimal outcome

[1] The minimum effort games can be used to model collaboration among individuals (Alós-Ferrer and Weidenholzer, 2014; Van Huyck et al., 1990).

[2] By conducting laboratory experiments with a minimum effort game, Weber (2006) shows that slow growth and exposure of entrants to previous norms can alleviate the problem of large group coordination failure.

[3] Given that social and economic networks are described precisely as undirected graphs, Seidman (1983) proposes that the minimum degree of all nodes can be used as a measure of network cohesion.