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Strategies and evolution in the minority game: A multi-round strategy experiment

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A B S T R A C T

Minority games are a stylized description of strategic situations with both coordination and competition. These games are widely studied using either simulations or laboratory experiments. Simulations can show the dynamics of aggregate behavior, but the results of such simulations depend on the type of strategies used. So far experiments provided little guidance on the type of strategies people use because the set of possible strategies is very large. We therefore use a multi-round strategy method experiment to directly elicit people's strategies. Between rounds participants can adjust their strategy and test the performance of (possible) new strategies against strategies from the previous round. Strategies gathered in the experiment are subjected to an evolutionary competition. The strategies people use are very heterogeneous although aggregate outcomes resemble the symmetric Nash equilibrium. The strategies that survive evolutionary competition achieve much higher levels of coordination.

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1. Introduction

In many situations the payoffs of your actions depend on the decisions of others facing exactly the same problem. A common feature on such occasions is that actions are strategic substitutes, i.e. an action taken by more people becomes less attractive. This occurs, for example, when firms need to choose whether to enter a new market, which (geographical) market to cater to, or whether to invest in a new technology. Other examples are traders deciding when to buy or sell a stock, commuters choosing a route and time to travel, workers deciding on union membership or high school graduates selecting a college program to enroll into. In such situations agents have to both coordinate and compete. Certainly if the agents are (nearly) symmetric, the payoffs for successful agents are large and there is no intuitive focal solution, one can imagine that coordination failure and instability can easily emerge.

The "minority game" (Challet and Zhang 1997) provides a very stylized, but intuitively appealing, way to model these types of problems. The minority game has an odd number of players who simultaneously have to decide between two options. Players who make the minority choice receive a reward, independent of the size of the minority, others receive no reward. Given the symmetry of the possible choices there is no reason to assume anything other than random choice in a one-shot interaction. Interesting behavior may however emerge when players interact repeatedly, as they often do in the situations the minority game aims to model.

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Even when the minority game is played repeatedly game theory provides only limited guidance. The game has many equilibria, none of which is focal. The pure strategy equilibria (any distribution of players across options leading to the largest possible minority) lead to very asymmetric payoffs and are non-strict.[1] The symmetric mixed strategy Nash equilibrium (with each player choosing each option with equal probability) is, by definition, also non-strict and may lead to small minorities, and hence suboptimal outcomes. All other equilibria are also non-strict and/or prone to suboptimal outcomes.

As game theory does not make any clear predictions about behavior in the minority game researchers have turned to simulation models and experiments to understand what happens in a repeated minority game. In simulation models different agents use different strategies to play the game repeatedly. A major drawback of this approach is that the strategies used in these simulation models are selected more or less subjectively by the researchers. Whether decision makers would actually use those strategies is unclear. Since the choice of strategies is a crucial determinant of the dynamic behavior of the game this is highly unsatisfactory. Some studies allow strategies to evolve over time depending on their performance, but even in these models outcomes depend on the initial population of strategies and the types of strategies considered.

Laboratory experiments on the minority game can shed some light on aggregate outcomes, but, due to the large strategy space, it is impossible to distill the exact strategies used by the participants. As a result it is also impossible to study long term dynamics and the effect of evolutionary pressure on the population of strategies.

To solve this problem we use a strategy method experiment to elicit explicit strategies in a repeated (five-player) minority game. After gaining some experience with the minority game in the laboratory, participants program a strategy. A computer tournament between all submitted strategies then determines a ranking (the participants who submitted the five highest ranked strategies receive a monetary reward). After participants receive feedback on the performance of their strategy in the computer tournament they can revise their strategy for the next round. They can program new strategies and run simulations with these new strategies and strategies of others from the previous round, to evaluate the performance of programmed strategies. There are five rounds in total, each separated by a week.

We first analyze and classify the strategies submitted by the participants. Subsequently we run an evolutionary competition with all (107 unique) strategies to see which strategies survive. We find that the strategies submitted lead to aggregate outcomes that are comparable to those under the symmetric mixed strategy Nash equilibrium. However, individual strategies are very diverse, as is their performance. Nevertheless, there are some properties common to many strategies; in particular a majority of the strategies employs randomization, something excluded in many simulation studies. After evolutionary competition between the strategies four, relatively simple, strategies survive and coordination is enhanced substantially.

The remainder of the paper is organized as follows. In the next section we discuss the minority game and review the computational and experimental literature on this game. Section 3 discusses the design of the experiment. In Section 4 we analyze the strategies submitted by the participants and in Section 5 we use these strategies to establish which of them survives in an evolutionary competition. Section 6 summarizes the results.

2. The minority game

2.1. Definition and relevance

The minority game was introduced by Challet and Zhang (1997) as a stylized version of Arthur's famous *El Farol* bar game (1994). Arthur considers a population of 100 people deciding whether or not to visit the El Farol bar which will only be a pleasant experience if at most 60 people go. The minority game is a symmetric version of the El Farol bar game. There is an odd number of players N, who simultaneously have to choose one of two sides (say *Red* and *Blue*). All players that make the minority choice are rewarded with one 'point', the others earn nothing. More specifically, let $s_i = 1$ when player i chooses *Red* and $s_i = 0$ when player i chooses *Blue*. Payoffs for player i are then given by

$$\pi_i(s) = \begin{cases} s_i & \text{when } \sum_{j=1}^{N} s_j \leqslant \frac{N-1}{2} \\ 1 - s_i & \text{when } \sum_{j=1}^{N} s_j \geqslant \frac{N+1}{2}. \end{cases}$$

Note that the minority game is one of the simplest games one can think of: there are only two actions to choose from and only two possible payoffs. Furthermore, the game is symmetric.

The one-shot minority game has many Nash equilibria. Any action profile where exactly $\frac{N-1}{2}$ players choose one side constitutes a pure strategy Nash equilibrium. There are $\frac{N!}{(\frac{N+1}{2})!(\frac{N-1}{2})!}$ of such pure strategy Nash equilibria, which is a substantial number even for moderate values of N. There also exists a symmetric mixed strategy Nash equilibrium, where every player chooses *Red* with probability 1/2. Finally, there are infinitely many asymmetric mixed strategy Nash equilibria. Take for example the profile where $(N-1)/2$ players choose *Red* with certainty, $(N-1)/2$ players choose *Blue* with certainty and the remaining player randomizes with any probability.

Because of the plethora of equilibria and the symmetry of the minority game players in a one-shot version of this game can do little more than randomly choose one of the options. However, when the minority game is played repeatedly interesting behavior may emerge. Players could converge to one of the many equilibria but all equilibria are likely to be

[1] Players in the majority are indifferent between the two possible choices.

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