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Repeated Game Strategies in Local and Group Prisoner's Dilemma

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Repeated Game Strategies in Local and Group Prisoners' Dilemmas Experiments: First Results*

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Abstract

We investigate and compare different approaches to derive strategies from observed data in spatial and spaceless prisoners' dilemmas experiments. We start with a model where players choose a fixed action that remains constant for all repetitions of a stage game. As an extension we then allow players to choose simple repeated game strategies that, however, remain fixed over the course of the game. We then discuss a method how to identify changing repeated game strategies. This method is used to study a simple reinforcement model. We find that in a spatial structure reinforcement plays a more important role than in a spaceless structure.

JEL-Classification: C72, C92, D74, D83, H41, R12

Keywords: Local interaction, experiments, prisoner's dilemma, reinforcement, repeated games.

1 Introduction

We investigate experimentally a prisoners' dilemma situation in a spatial and a spaceless model. Theoretically spatial prisoners' dilemmas have been studied by Axelrod [Axe84], Bonnhoeffer, Nowak and May [BMN93], Ellison [Ell93], Eshel, Samuelson, and Shaked [ESS98], Kirchkamp [Kir99], Lindgren and Nordahl [LN94], Nowak and May [MN92, MN93], Hegselmann [Heg94], Ely [Ely96] and several others. A brief discussion can be found in [KN00]. In this literature agents repeatedly use learning rules to choose strategies in repeated symmetric 2×2 games. These strategies can be stage game strategies (see [BMN93, Ell93, ESS98, MN92, MN93]) or repeated game strategies (see [Axe84, Kir99, LN94, Heg94]). Modelling players' behaviour as determined by repeated game strategies is a more general, and, in particular in the

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context of prisoners' dilemmas, a more adequate approach. However, in the experimental literature the application or analysis of repeated game strategies are sparse. Spaceless structures have been analysed in [SMU97] or [Axe84]. Experimental studies of spatial situations (see [KEB97, KEB98, KN00]) restrict their analysis to only stage game strategies. In this article we attempt to extend the experimental literature in considering also repeated game strategies. These repeated game strategies will be simple and of the following type: Cooperate if the number of cooperating neighbours is larger than a certain threshold. The threshold may be different for each player and may or may not change over time.

We will describe the experimental setup in section 2. We then introduce repeated game strategies allowing players to condition on past behaviour of their opponents. We start with a simplified version that assumes constant repeated game strategies for each player in section 3. This simple model explains the experimental data already better than a model with constant stage game strategies. However, with these constant and simple repeated game strategies we can not explain all observations. We therefore study a more elaborate model in section 4 where repeated game strategies may change over time. This allows us to study reasons why repeated game strategies may change. We relate changes in repeated game strategies to payoffs using a simple reinforcement approach in section 5. We find that past success of strategies plays a role to a much larger degree in a spatial structure than in a spaceless one. Section 6 concludes.

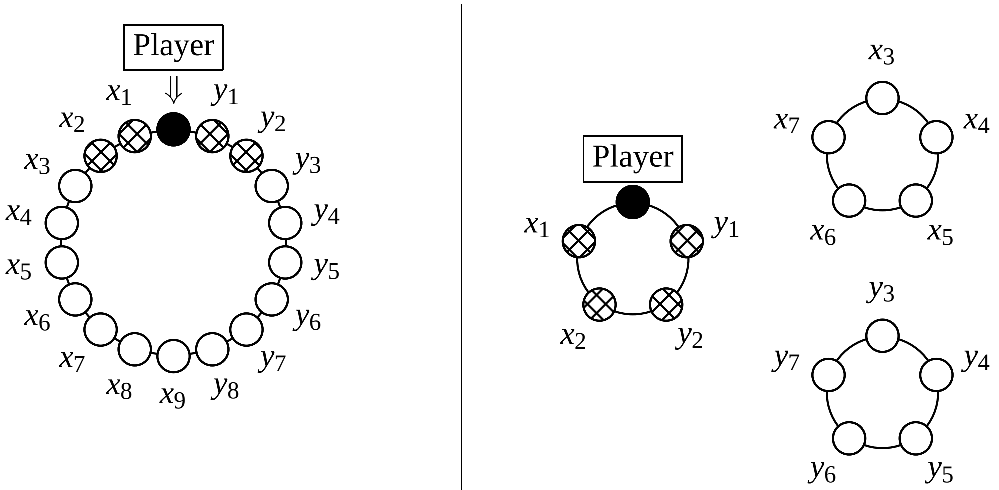
2 The experimental setup

In the following we outline our experimental setup. A more detailed discussion is given in [KN00]. All experiments were conducted at UPF in a computerised laboratory. We compare two structures, one that we will call 'circle', the other we will call 'group'. Circles model local interaction, groups model spaceless interaction. The structures are shown in figure 1. In each period players interact with two neighbours to the left (x_1, x_2) and two neighbours to the right (y_1, y_2). Players knew that they repeatedly interacted for 80 periods with the same neighbours. In each round each player had two choices: C or D.[1] Payoffs were a function of the player's own choice as well as the number of neighbours who chose C. The relation is shown in table 1. Players also obtained information about payoffs and strategies of their neighbours during each round. In order not to reveal the position of the neighbours this information was ordered by payoffs in each round. Thus, players only know what their neighbourhood as a whole did, they could not identify patterns in actions or payoffs of particular players.

3 A model with constant thresholds

Let us first assume that players follow a simple and constant repeated game strategy. Players cooperate if and only if the number of cooperative neighbours in the last ν periods was greater

[1] A game theorist might argue that we could have obtained more information had we asked participants only for one repeated game strategy for each repeated game. This argument presupposes that the submitted repeated game strategies would also explain the players' actions if the players could choose stage game strategies on a period to period basis. However, this is only true for perfectly rational players — and not for real participants of our experiment. One of the results of this paper is that players in the experiment seem indeed to change their repeated game strategies while playing a single instance of the repeated game.



Circle: spatial interaction of players through overlapping neighbourhoods

Groups: non-spatial interaction, all players are either in the same neighbourhood, or do not interact at all.

Figure 1: Neighbourhoods

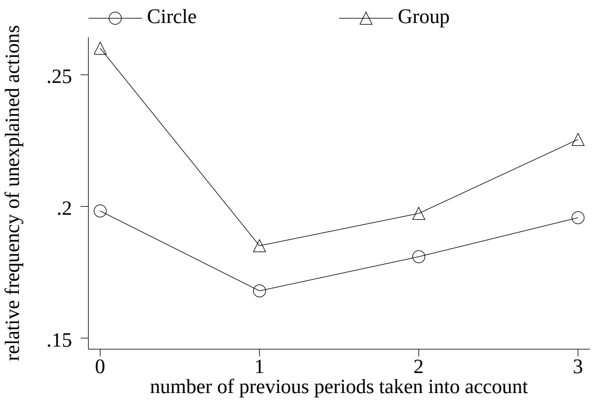
Payoff:					
own action	number of [neighbours / group members] choosing *C*				
	0	1	2	3	4
C	0	5	10	15	20
D	4	9	14	19	24

Table 1: Payoff Matrix

than a certain threshold $\tau \in \{0,1,\ldots,N+1\}$ where N is the number of neighbours.[2] A player with $\tau = 0$ will always cooperate, a player with $\tau = 1$ will cooperate if in the previous period at least one neighbour played C, ..., a player with $\tau = N$ will only cooperate if all neighbours cooperated in the previous period, and finally a player with $\tau = N+1$ will never cooperate. This last case may sound strange but it is only a convenient notation: $\tau = N+1$ means that in order to cooperate the player requires more neighbours than there actually are in the neighbourhood to play C. Since this can never happen, the player never cooperates.

The above strategies presume that cooperative behaviour of each player becomes more likely with an increasing number of cooperative neighbours.

For each player separately we determine the threshold value τ that maximises the number of correctly explained actions. If there is no unique such value we take one randomly from the set of maximising values. We do this separately for time-spans (ν) between 0 and 3. Figure 2 shows the relation between ν and the relative frequency of unexplained actions. With $\nu = 0$ predictions



All past periods are equally weighted.

Figure 2: Relative frequency of unexplained actions

assume a very simple strategy, players either always play C or they always play D. Actually the behaviour of most players (84.3%) is best approximated with all D. With such a model we can not explain 26% of the actions taken in groups, and 19.8% of the actions taken in circles. The higher rate of Ds in circles makes it easier to approximate players' behaviour. Introducing information about a single previous period ($\nu = 1$) improves the number of correctly predicted actions, in particular in groups. The improvement in circles is smaller, which is consistent with Kirchkamp and Nagel [KN00] who find less strategic interaction in circles than in groups. Introducing more periods ($\nu = 2$ or $\nu = 3$) does not improve the number of correctly predicted actions. Apparently only the previous period has a substantial impact. Introducing more and irrelevant periods deteriorates the quality of the prediction. We will therefore restrict ourselves in the following to the case $\nu = 1$.

[2] The reader should note that this approach weights experience from all past ν periods equally. Alternatively one could use discounting of past experience. Our approach seems, however, sufficient to show that only the recent past ($\nu = 1$) has a substantial impact.

Figure 3 shows for illustration the distribution of the threshold level τ under the assumption that τ is constant for each player. In groups we can easily distinguish two types of players: They

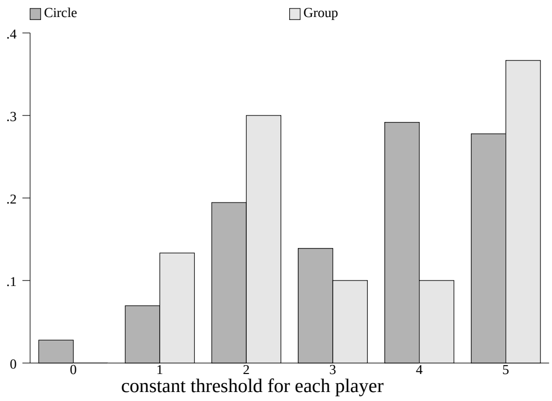


Figure 3: Threshold levels, constant for each player

either never cooperate ($\tau = 5$) or require a moderately cooperative neighbourhood ($\tau = 2$). 67% of all players fall into these categories. In circles, however, this distinction is much less clear. Only 47% of all players are of type $\tau = 5$ or $\tau = 2$. Many players are better described by some intermediate strategy.

Figure 4 shows how players' behaviour over time becomes increasingly consistent with this simple model. In the first periods of the experiment both in circles and in groups the simple

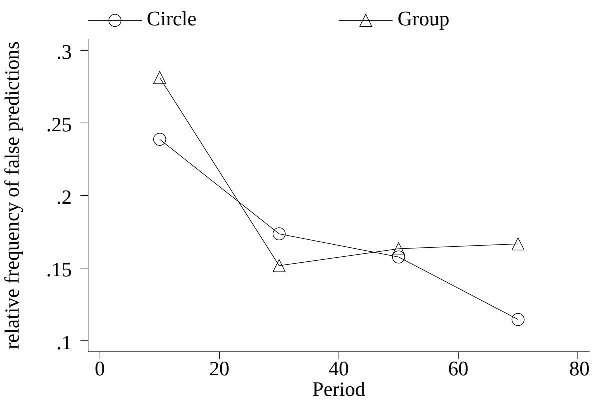


Figure 4: The number of false predictions decreases over time

model predicts badly. After about 20 periods, however, predictions become much better.

In appendix A we show the raw data and also how well the raw data can be predicted with such a simple model. Some of the unpredicted actions may be explained as experiments, but others (the more persistent ones) may better be explained through a repeated game strategy that changes over time. We will therefore allow for change of repeated game strategies over time in the next section.

4 Changing Repeated Game Strategies

In our experiment we only observe whether a player plays C or D. This behaviour could be explained with the help of a repeated game strategy, however, when attempting to identify a repeated game strategy that may change over time we face the problem that a given series of strategic interactions among agents can be explained by a infinite number of repeated game strategies of the individual agents.

Similar to the approach taken in section 3 we describe strategies with the help of a threshold value τ. This reduces that space of repeated game strategies but does not rule out the possibility that several thresholds τ explain at a given period a player's behaviour. To further identify τ we require that τ changes as little as possible. In other words, if there is a τ that explains the behaviour of a player not only at time t but also at time $t-1$ or $t+1$ we will favour this τ over another one that only explains the behaviour at time t.

Here is an example:

Period	…	$t-1$	t	$t+1$	…
Action in period t	…	C	D	C	…
number of C's in the neighbourhood in the previous period	…	3	2	4	…
possible τ	…	$0-3$	$3-5$	$0-4$	…

The example player chooses C in period $t-1$. In the previous period this player had 3 cooperative neighbours. It is possible that this player already cooperates with 2, or 1, or even 0 neighbours that play C. However, he obviously does not require 4 or 5, since, as we see, he already plays C with only 3 neighbours in the previous period. Therefore we can restrict the range of possible values for τ in period $t-1$ to $0\dots3$.

In period t this player chooses D. We know that our player had 2 Cs in his neighbourhood in the previous period. Hence, our player might have played C with 3, or 4, or 5 Cs, but 2 are apparently not enough. We assume that 1 or 0 are even worse. Thus, we can restrict the range of possible τs to $3\dots5$.

In period $t+1$ the player chooses C. In the previous period this player had 4 cooperative neighbours. It is possible that this player already cooperates with 3, or 2, or 1, or even 0 cooperative neighbours. However, he apparently does not require 5. Thus, we can restrict the range of possible values for τ to $0\dots4$.

In this example only the value $\tau=3$ explains all observations around t. This, however, is a lucky coincidence. With our data typically three subsequent periods do not allow to reduce the range for τ to a single value. We have to take into account more periods to determine a unique value for τ.

More formally we repeatedly apply the following algorithm:

Be $n(t)$ the number of cooperative neighbours of a player in period $t-1$. Be $I_0(t)$ the range of possible τs that is compatible with a players action in this period:

$$I_0(t)=\begin{cases}[0,n(t)] & \text{if the player plays } C \text{ in period } t\\ [n(t)+1,N+1] & \text{if the player plays } D \text{ in period } t\end{cases} \tag{1}$$

Notice that these intervals are never empty.

We distinguish the following conditions:

$$
\begin{array}{lcl}
a & : & I_k(t-1) \cap I_k(t) \cap I_k(t+1) \neq \emptyset \\
b & : & I_k(t-1) \cap I_k(t) \neq \emptyset \\
c & : & I_k(t) \cap I_k(t+1) \neq \emptyset \\
d & : & \min(I_k(t-1)) > \max(I_k(t)) \\
e & : & \max(I_k(t-1)) < \min(I_k(t)) \\
f & : & \min(I_k(t+1)) > \max(I_k(t)) \\
g & : & \max(I_k(t+1)) < \min(I_k(t))
\end{array}
$$

We now iteratively reduce the size of the intervals using the following method:

$$
I_{k+1} = \begin{cases}
I_k(t-1) \cap I_k(t) \cap I_k(t+1) & \text{if } a \\
I_k(t-1) \cap I_k(t) & \text{if } \neg a \wedge b \\
I_k(t) \cap I_k(t+1) & \text{if } \neg(a \vee b) \wedge c \\
\max(I_k(t)) & \text{if } \neg(a \vee b \vee c) \wedge d \\
\min(I_k(t)) & \text{if } \neg(a \vee b \vee c \vee d) \wedge e \\
\max(I_k(t)) & \text{if } \neg(a \vee b \vee c \vee d \vee e) \wedge f \\
\min(I_k(t)) & \text{if } \neg(a \vee b \vee c \vee d \vee e \vee f) \wedge g \\
I_k(t) & \text{otherwise}
\end{cases} \tag{2}
$$

Before we discuss these conditions in more details, we should note two things:

- Once an interval consists of a singleton it will never change through repeated application of the above algorithm.
- Intervals can only become smaller, never larger. Formally $\forall_{j>k} I_j(t) \subseteq I_k(t)$. I.e. we never add something to a strategy of a player, we only make it more precise. The resulting strategy will always be compatible with what we have observed.

Condition a is the simplest and most frequent case: The ranges for τ in three subsequent periods are consistent and allow for one or possibly more values of τ. In this case we take the intersection of these ranges.

If such an intersection would be empty we try to find only two subsequent periods. We first look more into the past (b) and then more into the future (c).

If this fails as well, then neighbouring ranges for τ do not intersect at all. In our interpretation this means that we have detected a change in the conditional strategy of the player. We then assume some inertia and shrink the interval for τ_t into the direction of the neighbouring interval. We do this first for $t-1$ (conditions d and e) and then for $t+1$ (conditions f and g).

When for all players in the experiment and for all periods $I_{k+1} = I_k$ then we have reached a fixed point of the process. We will call these intervals I^*. Notice that with a finite number of observations the process always reaches a fixed point in a finite number of steps.

Will this process converge to only singletons? It is possible to show that if there is some randomness in players' behaviour which is not perfectly correlated with the behaviour of the neighbours then the probability to obtain a unique τ grows arbitrarily close to 1 when the number of observations per player (number of periods in our experiment) is only large enough[3].

[3] To see this, one has to show that if $I_k(t)$ is not a singleton then $I_{k+l}(t)$ will be a singleton if only we find a t'

Since we have a finite number of observations in our experiment we only obtain a unique τ for about 90% of all players and periods. To make the analysis simpler we reduce intervals to a random integer within the interval for the remaining 10%. This is only a technical simplification that does not affect results.

In appendix A we show for each player the development of the threshold τ over time. Let us start here with some summary statistics. Figure 5 shows the development of the threshold level

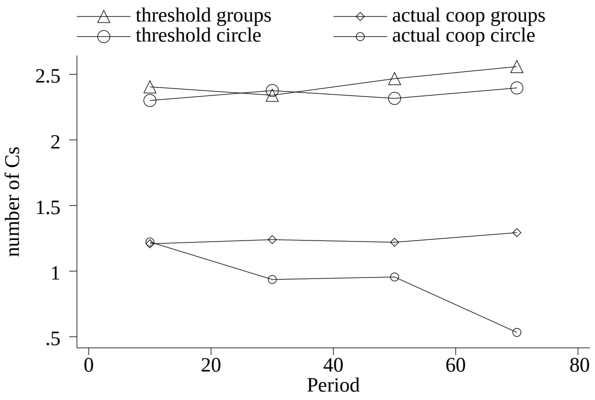


Figure 5: Threshold level and level of cooperation

τ over time in groups and in circles separately, together with the average level of cooperation. We see that players both in groups and in circles have a common threshold τ of about 2.5. This threshold does not depend on the structure. Average cooperation levels are much lower (between 0.5 and 1.2) and depend on the structure.

Figure 6 shows the increase in τ from period to period depending on the change in the number of cooperative neighbours from the previous period to the current period. We have only a very small number of observations for the borderline cases, hence, we should concentrate on the center of the diagram. We see that in circles players adapt quickly. An increase in the number of cooperative neighbours is answered with a decrease in the own threshold. A decrease in the number of cooperative neighbours yields an increase in the own threshold. In groups, however, the threshold level is not influenced by changes in the number of cooperative neighbours. This observation can be confirmed by running a robust regression of changes in threshold on changes in the number of cooperative neighbours. Allowing for correlated observations within sessions an F-test reveals no significant relation between the two variables for the group case ($P > 0.50$), however a highly significant relation ($P < 0.025$) for the circle case.

We interpret this finding as follows:

- The description of players' behaviour in groups is satisfactory. Adding another variable does not improve its explanatory power. Threshold levels seem to be exogenously given.

such that $I_k(t) \cap I_k(t')$ is a singleton. In this case $l \leq |t' - t|$, i.e. the above process will converge to a singleton in at most $|t' - t|$ steps. To ascertain the existence of such a t' we need the assumptions of randomness in players' behaviour together with a large enough number of observations.

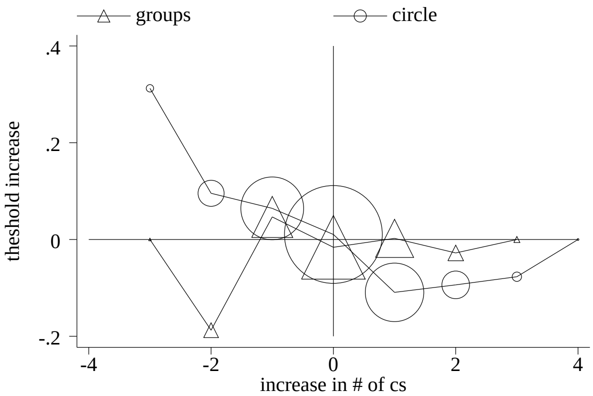


Figure 6: Change of threshold level depending on the change in the number of cooperative neighbours.
Sizes of the symbols are proportional to the number of observations.

- The description of players' behaviour in circles is not complete. Adding another variable to the model improves its explanatory power. The threshold level changes with a variable that is endogenous to the model.

In the next section we attempt to explain this endogenous change.

5 A simple reinforcement model

We interpret now the value of the threshold τ as a repeated game strategy. We assume that each player in each period associates with each possible value of τ a discounted average payoff of this strategy. Reinforcement (see Erev and Roth [ER98]) suggests that players are more likely to switch to a strategy that was successful in the past.

Figure 7 shows for each period the average number of different threshold levels players have experienced up to this period. We see that relatively soon the average player has experience with four different repeated game strategies. This is less than the maximal number of six in this case, but allows us to explain his choices with the help of comparisons of payoffs. To do that we concentrate on the situation when a player switches from one repeated game strategy (the 'source' strategy) to another (the 'target' strategy). For each player we calculate for each period and for each repeated game strategy the discounted[4] payoff while using this strategy up to this period. The difference between the payoff of the 'target' strategy and the 'source' strategy is shown in figure 8. For both the 'source' and the 'target' strategy we can use past payoff experience with this strategy to calculate average payoffs of this strategy. We see that the average difference is always higher on circles than in groups, i.e. switching from one strategy to another is more payoff-driven in circles than in groups. We also see that for small thresholds ($\tau \leq 2$ on circles, $\tau \leq 4$ in groups) the average difference between 'target' and 'source' payoffs

[4] As a discount factor we use 0.9.

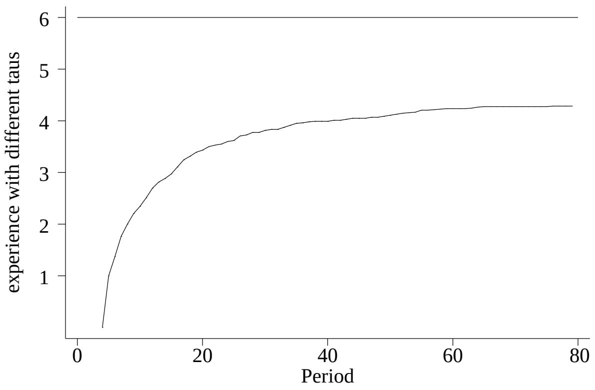


Figure 7: Average number of different threshold levels players have experienced

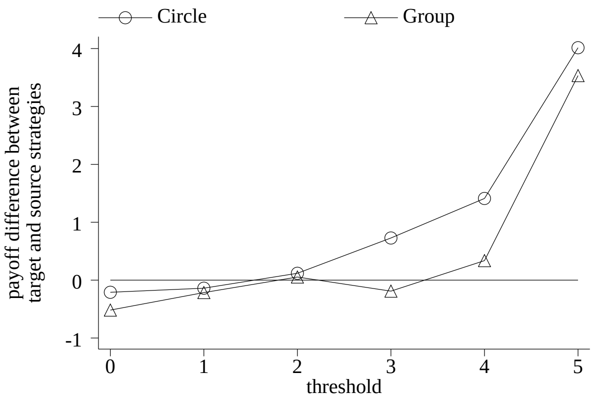


Figure 8: Average difference in payoffs between target and source strategy

is very small, sometimes even negative. Apparently switching in this range is driven not by past payoffs but other motives. Speculation for reciprocity might be one of them.

6 Conclusion

We model players' repeated game strategies with the concept of a threshold value for cooperation. The threshold is defined by the number of cooperating neighbours needed in order for a player to cooperate.

In a first step we study a model with constant thresholds. Such a model has more degrees of freedom than a (constant) stage game strategy based model and, hence, can explain more observations. We find, however, that players' behaviour can better be explained when the threshold is allowed to depend on the number of cooperative neighbours or payoffs.

We study a simple reinforcement model and find that strategies that were successful in the past are indeed more likely to be played. We observe that players change their threshold more rapidly in a local interaction structure than in a spaceless interaction structure.

As a consequence a decrease of cooperation by neighbours follows an increase of threshold which leads to less cooperation on the circle than in the groups.

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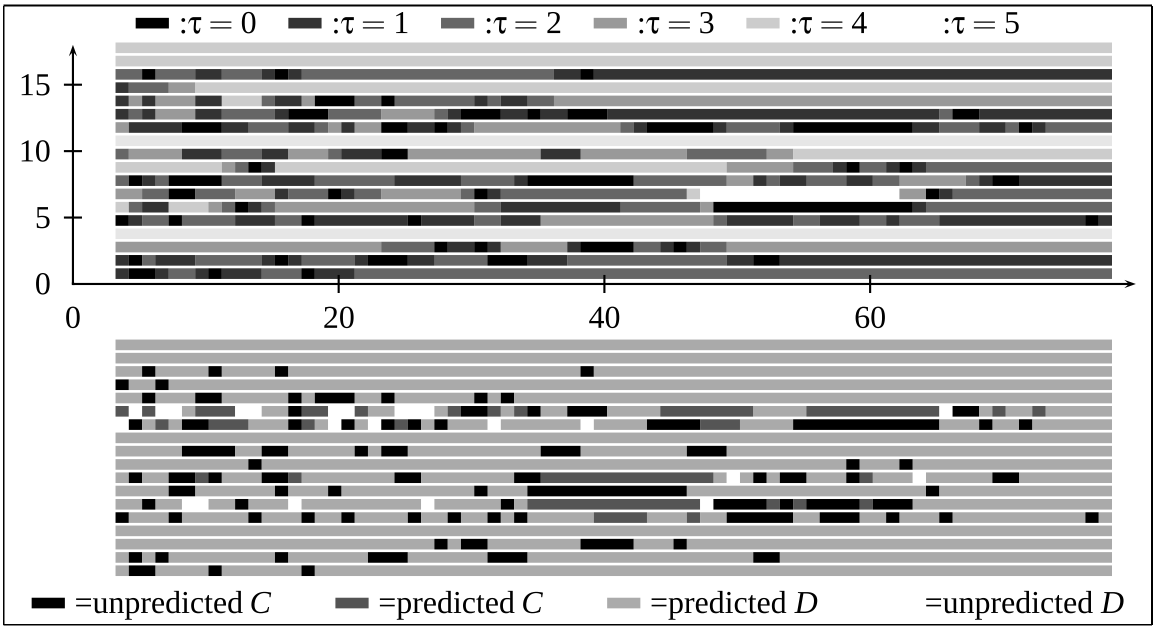
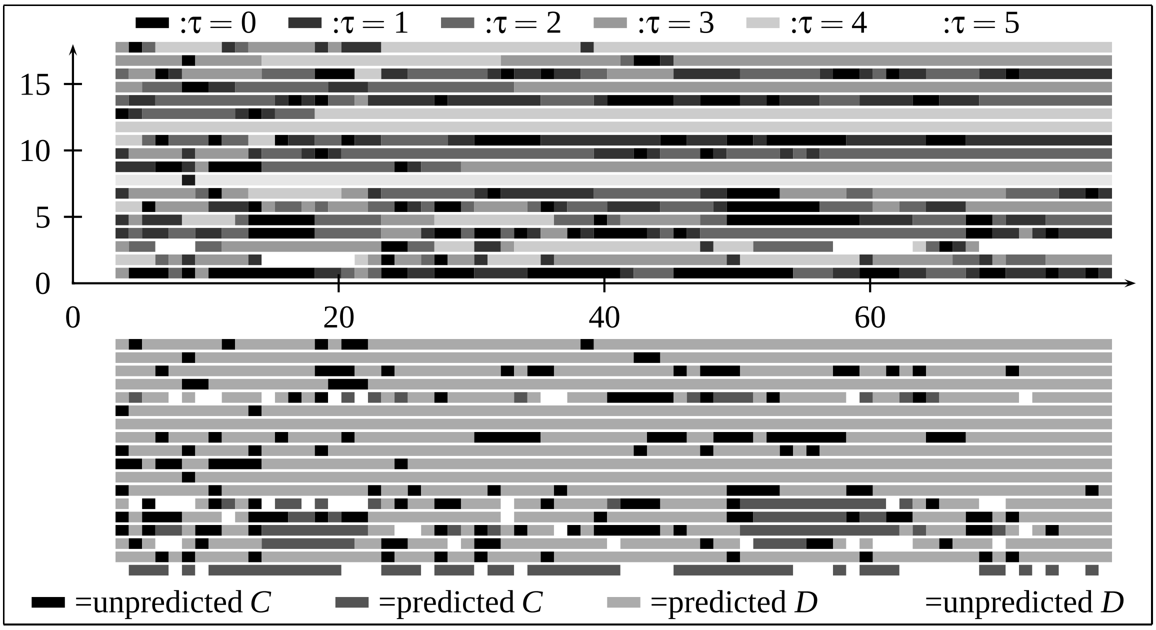
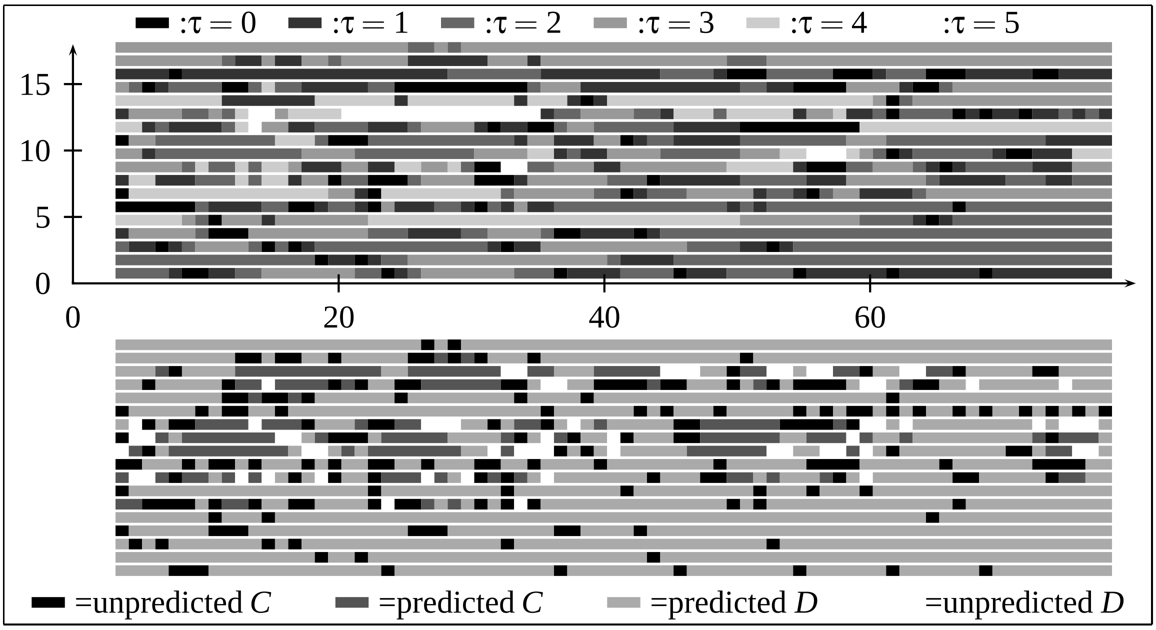
A Raw Data

Each experiment is represented by two graphs. The top graph for each experiment shows τ for each period and each player, the bottom graph shows the choice of C or D. To illustrate the explanatory power of the threshold model we distinguish in the bottom graph between predicted and unpredicted Cs and Ds. We do this as follows: We find for each player a (constant) threshold value that explains the highest possible number of Cs and Ds. Those Cs and Ds that can not be explained with this constant threshold value are ‘unpredicted’, the others are ‘predicted’.

A.1 Experiments on Circles






:τ = 0
:τ = 1
:τ = 2
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:τ = 4
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15
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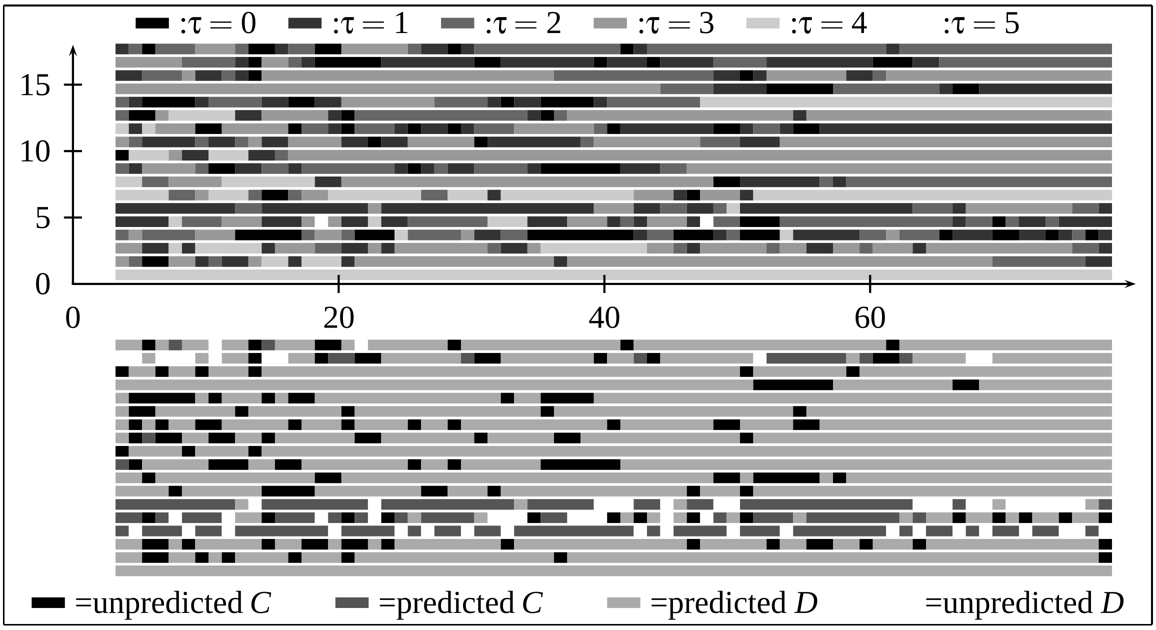
:τ = 0
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:τ = 4
:τ = 5
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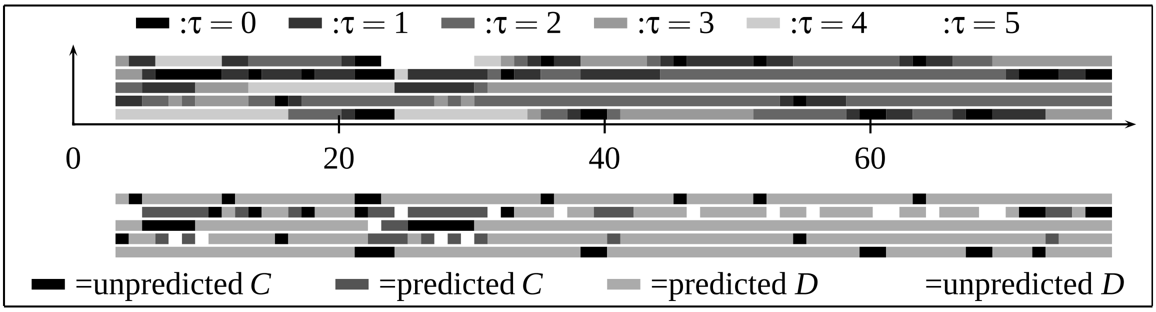
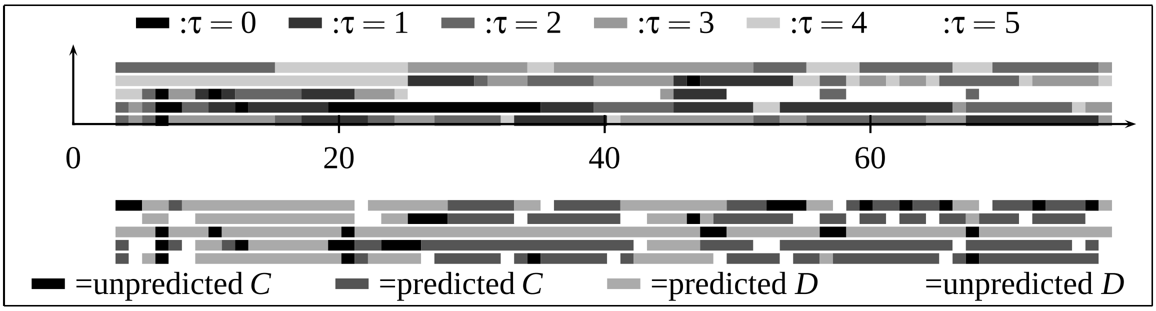
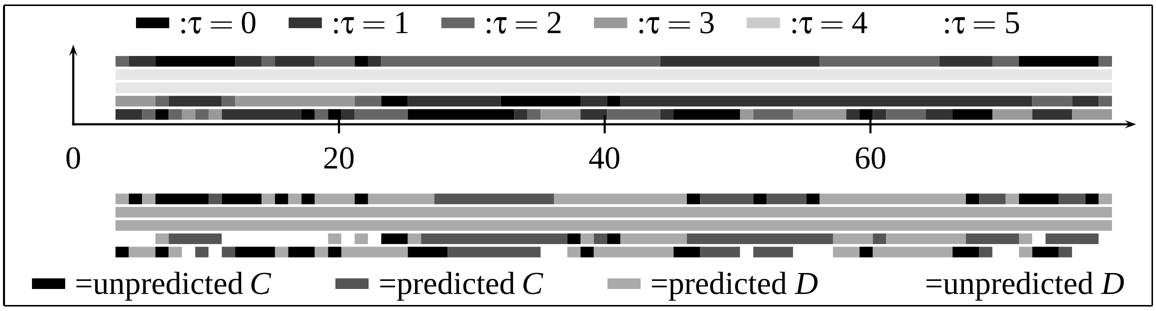
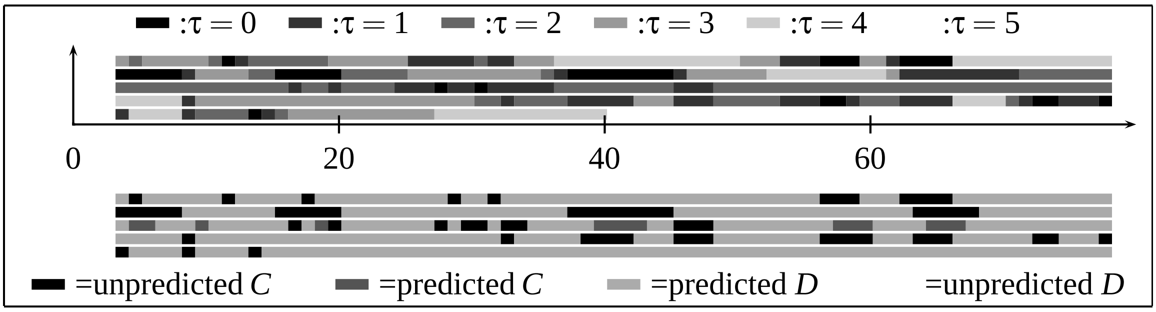
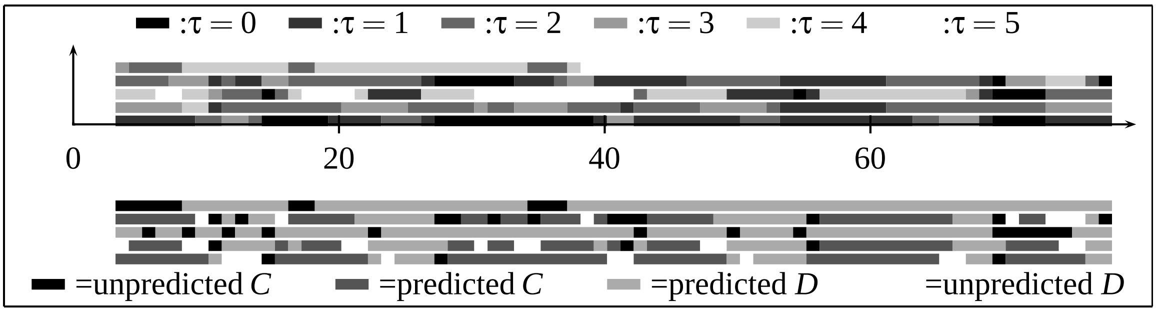
A.2 Experiments in Groups

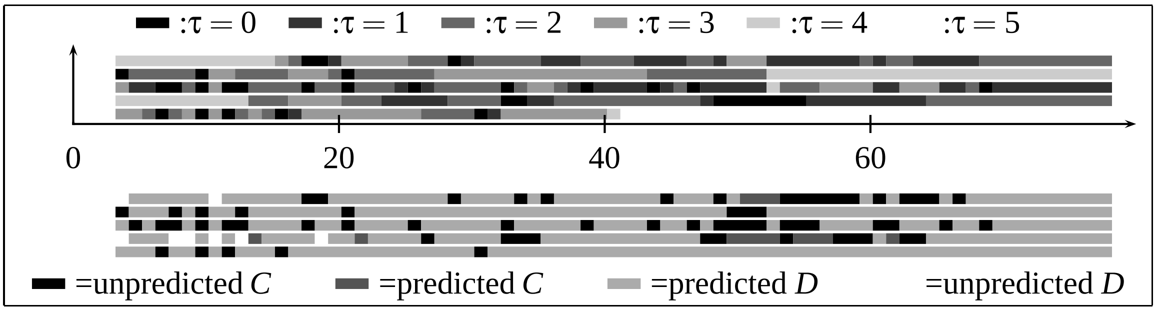












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