Evolution of Conditional Cooperation in Prisoner's Dilemma*

Ali Seyhun Saral†

January 12, 2021

Note: This is a draft. While the content and the analysis of the paper are unlikely to change, this version is likely to contain mistakes and typos. For the latest version of the paper please refer to my web page: `http://www.saral.it`.

Abstract

Conditionally cooperative preferences have been proposed as one of the main drivers of cooperation, as well as the reason for the decline in social dilemma experiments. Understanding the dynamics of cooperation generated by these preferences is vital to promote sustainable cooperation. Numerous studies showed that the majority of experimental subjects show conditionally cooperative preferences. And most the participants can be categorized into three types: conditional cooperators, self-maximizers and hump-shaped (triangle) cooperators.

In this study, I investigate the role on conditional strategies and their evolutionary success in an extended Prisoner's Dilemma Game. I show that, when the agents are likely interact in a population and a high level of cooperation is achievable, the most successful strategies are those

*Scripts for the simulations are available on the GitHub repository: `https://github.com/seyhunsaral/evolutioncc`

†Max Planck Institute for Research on Collective Goods, Bonn, Germany.

who employ an *all-or-none* type of conditional cooperation, followed by perfect conditional cooperators. When the likelihood of interaction is in an intermediate level, however, *hump-shaped* contributor types are the ones that are most likely to thrive, followed by imperfect conditional cooperators. The study provides a tractable reasoning of the success of particular conditional stragegies. Among these results, I illustrate existence of hump-shaped type of cooperators with a purely payoff-based reasoning, as opposed to previous attempts to explain this strategy with psychological mechanisms.

Keywords: reciprocity | conditional cooperation | reactive strategies | hump-shaped contributors

Introduction

Humans are distinct in their cooperation capabilities, if not unique (See Bowles and Gintis, 2011; Wilson, 2012). As a species, we heavily depend on the mutual cooperation of individuals. At first glance, from an evolutionary perspective, it seems counter-intuitive for individuals to cooperate in an enviroment in which cooperation is costly and free riding is beneficial: any fraction of free-riders would better beter off than those who cooperate, and would therefore have a higher evolutionary fitness. Since it would be easy to exploit the cooperators in such a population, it is just matter of time for cooperation to be eradicated. Then, how come cooperation is so common in some species including us humans?

A wide range of theories have been put forward to explain this puzzle.[1] One of the most prominent answers has been reciprocal altruism (Trivers, 1971; Axelrod and Hamilton, 1981; May, 1987; Nowak and Sigmund, 1992, 1993). Given that there is a positive probability for individuals to interact again, if the benefit of an aid is sufficiently greater than its cost, then cooperation of unrelated individuals can arise. In game theory literature, Folk theorems show that, if the threat of defection is present in the future, cooperating today is more

[1] See Nowak (2006); Bowles and Gintis (2011); Henrich and Muthukrishna (2021) for a review.

beneficial; therefore, a cooperative strategy in the stage game, as well as any other individually rational strategy, can be the equilibrium of the supergame (Friedman, 1971; Fudenberg and Maskin, 1986). Moreover, Axelrod's simulations on the Prisoner's Dilemma support those theoretical results by showing that the reciprocal *tit-for-tat* is a strong strategy that allows cooperation while it is immune to exploitation by selfish players (Axelrod, 1980a,b; Axelrod and Hamilton, 1981).

The main dynamics of cooperation through reciprocity can be summarized as follows: reciprocators cooperate among each other as they reciprocate kindness over time. Therefore they receive a higher payoff than the selfish types who meet other selfish types. And when a reciprocator meets a selfish type, the reciprocator responds selfishly after the first defection. Thus, the exploitation of a reciprocator by a selfish individual is not sustainable when the probability of future interaction is sufficiently high.

Howver, empirical evidence on the Prionser's Dilemma and the Public Goods Game draws a rather different picture: cooperation tends to decline over time, whether subjects play the game within the same group or matched with others (Selten and Stoecker, 1986; Andreoni et al., 1993; Cooper et al., 1996; Ledyard, 1994; Kim and Walker, 1984; Isaac et al., 1985; Andreoni and Croson, 2008). This declining trend in the Public Goods Game is often, and arguably best, explained by conditional preferences. The evidence was provided by Fischbacher et al. (2001), who collects conditional choices of subjects to the common pool by using the strategy method. According to their results, most of the participants reveal a preference pattern, in which they will only contribute if the others contribute as well, albeit with a *selfish bias*; they tend to contribute less to the public pool than the the average contribution by others. Conditionally cooperative preferences has been documnted widely, although those type of conditional strategies is not sufficient to sustain cooperation, as contributions tend to decline over time (Kocher et al., 2008; Herrmann and Thöni, 2009; Neugebauer et al., 2009; Fischbacher and Gächter, 2010; Chaudhuri, 2011; Hartig et al., 2015; Andreozzi et al., 2020)

Conditional Cooperation and Evolutionary Game Theory

Early models based on conditional strategies were investigated in disciplines which employ game-theoretical approaches, such as biology and political science. Axelrod's research showed the success of *tit-for-tat*, a strategy beginning with cooperation in the initial interaction and then copying its opponent's from the previous period (Axelrod, 1980a,b; Axelrod and Hamilton, 1981). An analogy of a tit-for-tat strategy in a Fischbacher-Gächter framework would be a perfect-conditional-cooperation strategy that matches the individual's contribution to the contribution by others. One should expect this kind strategy to be employed in real-life decisions due to its alleged success. In the experiments, however, perfect-conditional-cooperators are outnumbered by imperfect conditional cooperators who tend to give less than what others give. Reciprocity by imperfect conditional cooperators is not enough to sustain cooperation, not just within other commonly observed conditional types, but also when they interact among each other (Fischbacher and Gächter, 2010). Moreover, later results showed that the tit-for-tat strategy was vulnerable when mistakes happen: when an accidental decline occurs, tit-for-tat was not able to reestablish cooperation back again, unless another mistake corrected it (Hirshleifer and Coll, 1988; Selten and Hammerstein, 1984; Fundenberg and Maskin, 1990; Nowak and Sigmund, 1993).

A related line of research with conditional strategies was mostly investigated in biology. So-called "variable investment models" provided more insights into successful conditional-like strategies in social dilemmas. These models differ considerably from conditional strategies defined in a Fischbacher-Gäcther framework, as well as from each other by their assumptions; therefore it is not straightforward to compare their results.[2] For instance, in Doebeli and Knowlton (1998), the agents are characterized by two parameters; a parameter that defines

[2]See Sherratt and Roberts (2002) for a review of some early papers.

the unconditional altruism, and another defining the amount of reciprocation proportional to the difference between one's own altruism and that of the other. In their setup, they use a continuous altruistic investment game in which the marginal benefit of altruism decreases. Their evaluation of the success of their strategies takes pairwise comparison into account with the mutants of that strategy. They show that, unless a spatial structure is assumed, selfish types are the most successful ones. Roberts and Sherratt (1998) use a different agent definition in which costs and benefits are linear and investments can increase. They take representative strategies for a tournament: *Non-altruistic* agents, who do not invest at all; *Give-as-good-as-you-get* strategies, which invest as much as the other; *raise-the-stake* strategies, amplifying the investment, *short-changer* strategy, which gives less to the other than what the other gives, *all-or-nothing* strategy, which gives an amount and amplifies it only if other reciprocates as much or more. Roberts and Sheratt find that the raise-the-stake strategy is a stable cooperator as it cautiously invests but repeated interactions allow it to reach high cooperation levels.

Wahl and Nowak (1999a,b) provide a framework of reactive strategies under adaptive dynamics by providing a linear and continuous extension of the Prisoner's Dilemma in which different amount of contributions are possible. In their framework, they define a reactive strategy with three parameters: the initial move, the slope of the reaction function, and the intercept of the reaction function. Their results suggest that the initial move is a decisive factor in terms of success of a strategy. Moreover, Wahl and Nowak conclude that strategies that are generous, uncompromising and optimistic (in terms of initial move) are the most successful ones. An important result of those studies is that they demonstrate cycles of cooperation and defection over time. Indirect invasions deter reciprocal strategies which are normally resistant to direct invasion: more cooperative and/or compromising strategies are able to invade reciprocal strategies as those types are exploitable. That allows the invasion of the population by selfish types.

van Veelen et al. (2012) uses a generalized computational model. They run simulations of a Prionser's Dilemma game with finite automata. Their strategies can evolve to be reactive strategies or strategies that consider several rounds of histories depending on the complexity of the strategy generated by mutations. Moreover, their model investigates different levels of assortativity in the population structure. They show that reciprocity and population structure can jointly work in favor of reciprocal strategies. However, reciprocity itself is not sufficient to create and to foster cooperation with random interactions.

Considering these theoretical and computational results on conditional cooperation and reactive strategies, the following question arises; if we consider the set of strategies with those conditional strategy classifications defined by Fischbacher et al. (2001) framework, how likely would it be for cooperation to arise, and which particular strategies would be more successful than the others?

The two closest approaches to this study are Szolnoki and Perc (2012) and Zhang and Perc (2016). Szolnoki and Perc (2012) use a spatial structure to investigate conditional cooperation in Public Good Games. Their agents condition on the number of cooperators rather than the strategies themselves. The authors found that the more cautious conditional cooperators enable high levels of cooperation and limit the outreach of defectors by surrounding them spatially.

Zhang and Perc (2016) investigates the evolution of conditional types in a Public Goods Game in an agent-based model. The strategies their agents use are a combination of continuous and discrete functions. In their setup, a multilevel selection procedure is used. They found that the most successful type is the conditional cooperator type that contributes nothing up to a mid-level contribution by others, but increases its contribution gradually to the full cooperation when others agents' average contribution is maximum. This type of strategy can be considered as "all-or-nothing" type of strategy.

As we draw the general picture, there are certain regularities and mixed results in the literature. Those related with our research questions can be summarized as the following:

- Cooperation and defection strategies are likely to oscillate in most settings, especially without certain assumptions in the population structure. In Prisoner's Dilemma game, no pure strategy is evolutionary stable, and reactive strategies are vulnerable to indirect invasions.(van Veelen, 2012; van Veelen et al., 2012) Therefore, those strategies that use a mixture of actions need further investigation.

- When there is room for mistakes, it is often unclear how the results obtained by simulations align with theoretical expectations.

- There is a certain degree of mismatching between the actual behavior in experiments and the theoretical predictions in the framework of conditional strategies.

This study aims to fill this gap by demonstrating the success and estimating the likelihood of conditional strategies. In this study, I investigate the conditional preferences in the framework of Fischbacher et al. (2001), using computational methods. I examine the evolutionary success of those conditional strategies in a social dilemma with a simplified framework. I create populations of agents with the types drawn from of the set of all conditional strategies within our framework. Each agent randomly pairs with another agent to interact in this social dilemma, and continues to interact with probability δ. I simulate an evolutionary reproduction mechanism based on the success of the strategies shape the population structure and I examined success of those strategies for different continuation probabilities δ.

The results can be summarized as follows: selfish and close-to-selfish conditional cooperators are likely to be successful when the continuation probability is relatively low. Depending on the value of continuation probability, imperfect conditional cooperators who only fully cooperate when the opponent fully cooperates, perfect-conditional cooperators, and agents with hump-shaped contribution schedule are relatively successful when the continuation probability is sufficiently high. Unconditionally cooperating strategies are unlikely to survive even at high probabilities of continuation. And finally I conclude that the initial move aligned with the conditional strategy plays a crucial role in the survival of those conditional strategies.

Methods

This study focuses on the conditional strategies in a two-player social dilemma. The model I use has certain differences compared to those models in the literature which I referred in the previous section. First, I choose a setup that is closer to a standard game theoretical framework, in the sense that we do not assume a population structure, but instead use uniform random matching procedure for the agents. However the simulations can easily be extendable to such population structures. Second, I use a minimal setup which allows us to observe conditional strategies, ad defined by Fischbacher & Gächter framework and we avoid unnecessary computational complexities. I use an iterated Prisoners Dilemma with three strategies and discrete linear response functions that do not assume or limit the shape of the response functions. Moreover, I also control for the initial reactions, as it is often stressed that they play an important role on the path of the dynamics.

Linear Extension of the Iterated Prisoner's Dilemma

I use an extension of the Prionser's Dilemma game called Three-Actions Sequential Prisoner's Dilemma (3SPD) (Andreozzi et al., 2020). In this extended game, the three actions represent different cooperation levels: L (Low) refers to no cooperation/defection; M (Medium) refers to an intermediate cooperation level; and H (High) refers to full cooperation.

The cost of cooperation is c, while the benefit of cooperation to the opponent is b, with the constraint $b > c > 0$. If an agent plays the strategy L, this agent keeps the endowment for themself and no change will occur in payoff of the opponent. If the agent plays the strategy H, this agent pays the cost c and their opponent gets the benefit b. If the agent plays M, this agent will only pay the half the amount of the cost of full cooperation but the benefit to the opponent will be half as much as well, i.e., the agent pays a cost of $c/2$, while the opponent gets the benefit $b/2$.

The normal-form representation of the game is shown in Table 1. For the simulations, I used the following parameters: the cost of cooperation c is equal to 1, the benefit of cooperation b is equal to 2, and we set the base payoff to 1 to avoid negative payoffs. The normal-form representation of the game with those parameters is shown in Table 2.

		Player 2		
		L	M	H
	L	$(0,0)$	$(\frac{b}{2}, -\frac{c}{2})$	$(b, -c)$
Player 1	M	$(-\frac{c}{2}, \frac{b}{2})$	$(\frac{b-c}{2}, \frac{b-c}{2})$	$(b - \frac{c}{2}, \frac{b}{2} - c)$
	H	$(-c, b)$	$(\frac{b}{2} - c, b - \frac{c}{2})$	$(b - c, b - c)$

Table 1: Extended Prisoner's Dilemma Game

		Player 2		
		L	M	H
	L	$(1,1)$	$(2,0.5)$	$(3,0)$
Player 1	M	$(0.5,2)$	$(1.5,1.5)$	$(2.5,1)$
	H	$(0,3)$	$(1,2.5)$	$(2,2)$

Table 2: Extended Prionser's Dilemma Game with Simulation Parameters b=2, $c = 1$ and the Base Payoff 1

In order to investigate conditional strategies' and their effect on cooperation in a two player game, I used a sequential game setting based on the iterated

Prisoner's Dilemma. In this game, for each pair, one of the players is randomly selected as the first mover and makes the initial move. At this point, the agent will bear the cost of the action and the opponent will benefit from this action, if any.

I use an infitely repeated game approach to the iterated Prisoner's Dilemma Game: After each round, the game continues with the probability of continuation δ.

In the first round, the first movers start with their initial move. Then if the game continues, second movers respond to what their match did in the previous round according to their conditional strategies. If the game further continues, the first-mover agents in the first round similarly responds to that action with their own conditional strategy.

Conditional Strategies

In our model, an agent is characterized by an initial and a conditional strategy. As our extended Prisoner's Dilemma has three possible actions (L, M and H), a conditional strategy has three components. We represent each strategy with four letters; the first letter separated from the rest with a hyphen. The first letter corresponds to the initial move of the strategy, where the other three letters denote the conditional responses to L, M, H respectively. Since, in our context, there are three possible actions for four different situations, in total there are 81 possible strategies(3^4). The set of all possible strategies and their classification can be found in the appendix.

Figure 1 is a demonstration of two conditional strategies in interaction. The left side shows the actions of the first agent represented by the blue color, while the right side shows the actions of the agent represented by the red color. The blue circle refers to the initial move of the left agent, while the blue arrows, pointing from the actions of the other agent to the agent's own actions, represents a conditional reaction. Similarly, for the red agent, the red circle represents the initial movement, and the arrows represent the conditional responses.

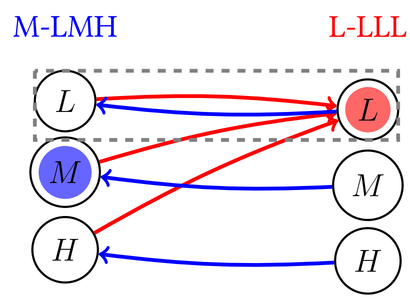

Figure 1: A Demonstration of the Interaction of Two Agents with Respective Conditional Strategies $M - LMH$ and $L - LLL$

As can be seen from the figure, the blue player has the action M as the initial move, and respectively he/she plays L if the opponent plays L, M if the opponent plays M, and H if the opponent plays H. Therefore, this type of the agent is denoted as $M - LMH$.

To give an example of the interaction, if the blue player is selected as the first-mover, it starts with the action M. The red arrow from that node points to action L of the red player, therefore the red player responds with L. If the game continues,the blue player responds with L and if it continues further, the red player responds with L, and so on.

Computational Model

In terms of the procedures of population generation, reproduction and mutation, I use a similar methodology with van Veelen et al. (2012). First, we generate a population with a fixed size of 200 agents. The type of the agents in this population are sampled from all 81 possible types. Each agent lives for one generation. In each generation, agents are matched in pairs randomly. After they are paired, the agents play the Extended iterated Prionser's Dilemma we described in the previous section. The interaction is repeated with probability δ. To reduce computational complexity, I sampled the number of interactions from a geometric distribution for each matching in each generation.[3] For each interaction, I normalize the payoffs by dividing the total payoff by the number of interactions in order to fix the effects of different delta values. After the interaction by two individuals are stopped, I resample the population according to payoffs; each agent is expected the have the offspring in the next generation with the probability that is equal to the proportion to its payoff to the total payoff. Therefore, agent $i \in N$ has the probability of resampling in the next generation $\dot{p}$:

$$\dot{p}_i = (\pi_i / \sum_{j \in N} \pi_j)(1 - p_M),$$

where π_l denotes the normalized payoff of individual l, N denotes the set of agents, and p_M denotes the probability of mutation. Each type has the same probability of taking place in the next generation through mutations.

We use Monte-Carlo method for our investigation: We repeat each simulation with the specific parameter for 500 times independently. That allows us to obtain the mean frequency of each action and each strategy in each parameter and generation over the total number of simulations. Then, these frequencies can be interpreted as the probability of an action/strategy to exist in a given parameter.

[3]The expected number of interactions for a given δ is $E[T] = \frac{\delta}{1-\delta}$. As the first interaction occurs with certainity in our setting, the expected number of interactions is $1 + \frac{\delta}{1-\delta} = \frac{1}{1-\delta}$.

Stage	Details
Population Generation	Number of Agents: 200 Uniformly from all possible types
Matching	Two players: random matching
Interaction	Extended iterated Prisoners Dilemma Continuation with probability δ
Reproduction and Mutation	Resampling proportional to normalized payoff Uniform random mutation with a fixed probability Ran for 5000 generations
Resampling	Regeneration of the population with the same parameters for 500 times

Table 3: Summary of the Computational Stages

In my model, each agent has a probability of making a mistake $p = 0.005$. This means, either as the first mover in the first interaction, in the later interactions, an agent plays a random strategy. Our results show that mistakes we introduce has minor effects on the rate of cooperation. The comparision of the simulation results between the case with mistakes and without them can be seen in Figure 6.

As the continuation probability δ is the key parameter we are interested in, we covered a range of values from 0.5 to 0.95 with increments of 0.05.

Results

To interpret the results I have obtained, first I start by demonstrating three single instances of our simulations for different delta values. Figure 2 shows the fraction of the actions that are being played in each generation, while Figure 3 shows the distribution of types in the same interaction.

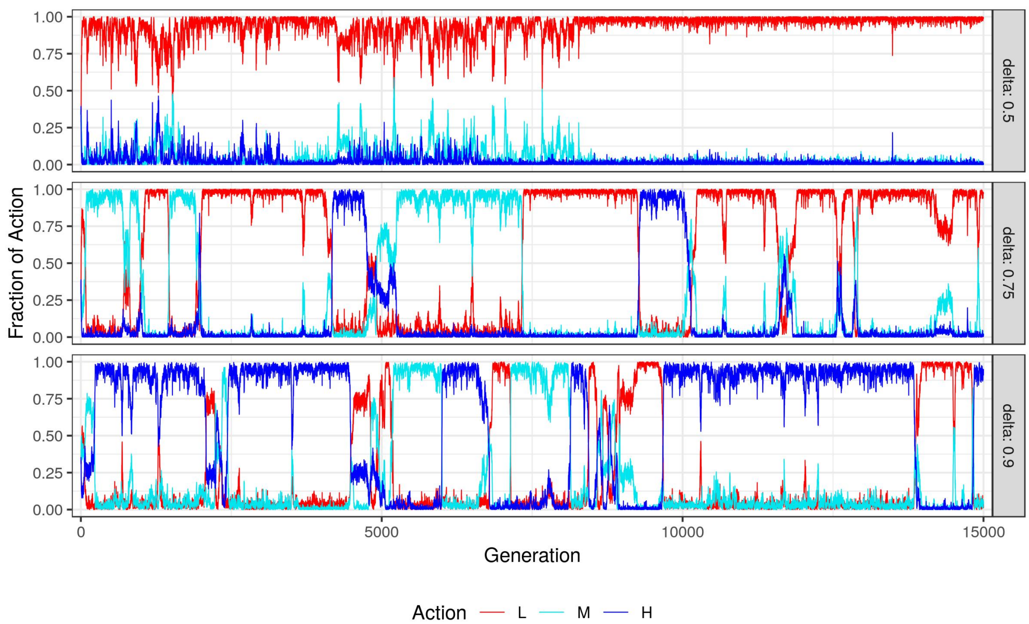

Figure 2: Fraction of Actions During Three Instances of Simulation with Different Continuation Probabilities

As can be seen from Figure 3, no type dominates the population for a long time. However, when δ is low, defection(L) outperforms cooperative strategies. In this case the types that are taking over the population are neutral mutants of the selfish type. When δ increases, occasional oscillations occur both in types and also in the actions. A single type takes over the population and stays as the most common type until another type with direct or indirect mutation takes over. This result is not unexpected, as no type is resistant to indirect invasion in a Prionser's Dilemma (van Veelen et al., 2012; García and van Veelen, 2016, 2018). But it gives us the intuition on how to interpret our result of resampled simulations. As cooperation and defection can occasionally occur, we should interpret the results in a probabilistic way rather than an expected state of a population.

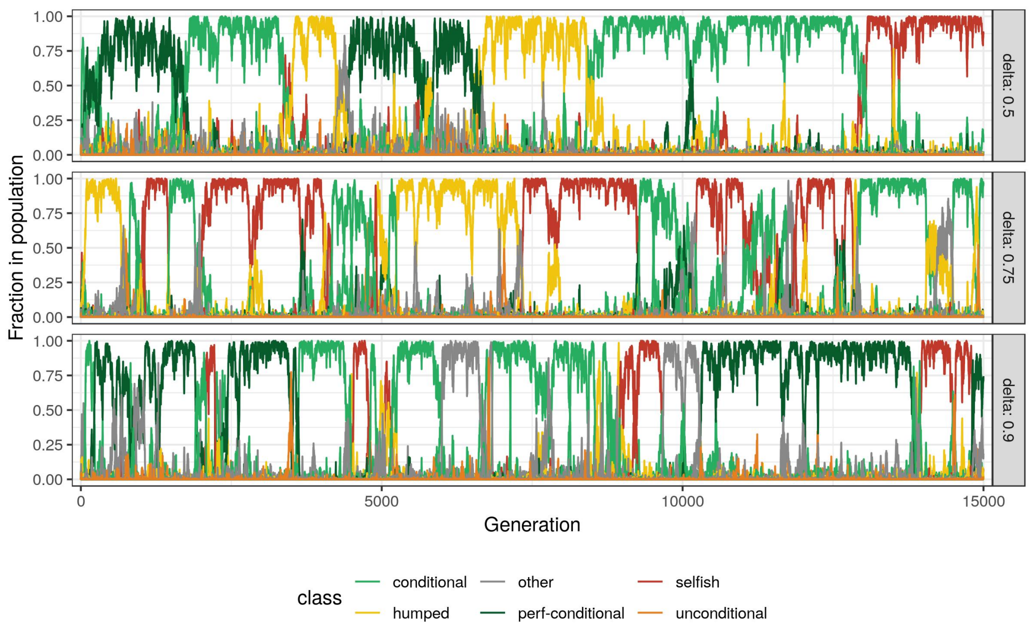

Figure 3: Fraction of Strategies During Three Instances of Simulation with Different Continuation Probabilities

Result 1 - Full cooperation is more likely to be obtained only at high values of continuation probability: Figure 4 shows the average fraction of each action; and similarly, Figure 5 shows the average fraction of each type for different values of continuation probability δ. Each value shown is an average of 500 simulations that ran over 5000 generations. Moreover, to reduce the effect of occasional drifts, we averaged last 2000 generations for which our simulations showed no great variation on the average values.

As δ increases, the existence probability of M and H gradually increases and the values of δ in which cooperation is more likely than defection is obtained only when delta is above a certain threshold. (For our parameters, $\delta > 0.75$, which is well above the theoretical threshold c/b. Hence, reciprocity is unlikely to promote cooperation below those values. Moreover, mid-cooperation, although being Pareto-inferior, is more likely to be obtained for those values.)

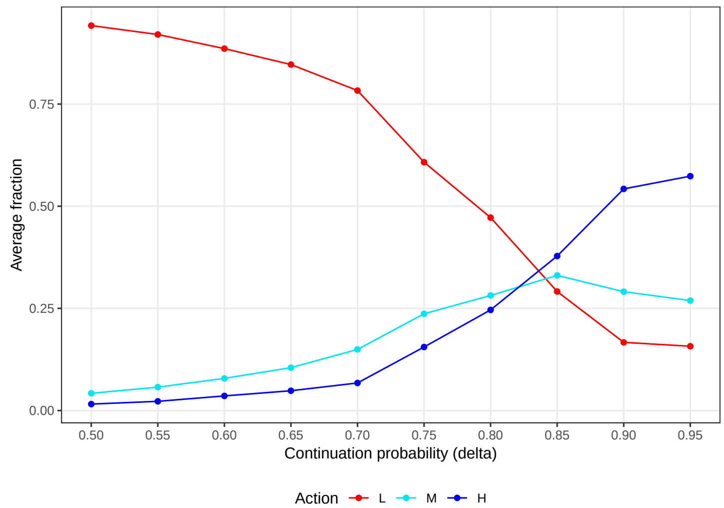

Figure 4: Average Fraction of Actions Over 500 Repetitions for Different Values of Continuation Probability δ

Focusing on Figure 5, we see that conditional types that are closer to selfish types are likely to exist in relatively lower values of δ, though it is unlikely for them to foster cooperation, but they rather likely to survive because they are neutral mutants when defection is a the common action in the population.

Result 2 - All-or-nothing cooperators are more likely to exist than perfect conditional cooperators: Figure 5 shows that, in all continuation probabilities, all-or-nothing cooperators with an optimistic start($H - LLH$) are more likely to exist than perfect conditional cooperators ($H - LMH$). Those two types are equivalent if we remove the medium level of cooperation. In this case, they both play a tit-for-tat strategy.

These strategies would do equally well when they play against each other in a deterministic setting: They would engage in full-cooperation(H), which would be adventageous for both types when the conditional cooperation probability is sufficiently high. However, when mistakes happen, all-or-nothing strategy is likely to exploit mistaken mid level cooperation(M) by others.

Result 3 - Initial move of a strategy is a determinant of the success of a conditional decision: Consider three strategies which are identical in their responses to the counterpart, but differ in their initial move: $L-LLH$, $M-LLH$ and $H-LLH$. All of these types, in an experimental study, would be classified as conditional cooperators. Our evidence shows that their success is highly dependent on the initial move. For instance, $L-LLH$ is relatively successful when δ is low and cooperation is unlikely. In this case, an opponent that plays H is unlikely to exist in the population, and the reaction of this strategy is L for all other strategies. This strategy does as good as the selfish the selfish strategy. However, agents using this strategy often fail to cooperate within each other, unless a mistake leads to high cooperation, as none of the two interacting parts initiate cooperation. The twin strategy that is successful in cooperating is $H-LMH$, but when the continuation probability is low, the first move of this strategy would cost a significant fitness that is impossible to tolerate with the cooperation within itself. When the δ is low and the population lacks a structure that gives a higher probability for similar agents to interact, this strategy fails to survive. The strategy $M-LLH$ has strong disadvantages both where δ is low, and it is sufficiently high to sustain cooperation.

Result 4 - Hump-shaped strategies are relatively successful: An interesting result I obtained is the relative success of hump-shaped cooperators. Such types of strategy are constantly observed in empirical studies, while the arguments regarding this type of behavior in those studies are still have been far from convincing.

In our simulations, we have two types of humped-shaped strategies that are likely to exist: $L-LML$ and $M-LML$. The former one is relatively successful due to its proximity to selfish strategy and virtually behaving as the same as the selfish agents when no cooperation is common in the population.

The latter one, however is a more interesting case. The reason begind the success of $M-LML$ strategy is due to its ability to coordinate in medium level of cooperation with a smaller cost than the other strategies. Moreover this strategy can exploit high-contributors as well. When the continuation probability δ is sufficient for cooperation to occur but still risky for high cooperation, this hump-shaped strategy is relatively successful.

Figure 5: Average Fraction of Strategies Over 500 Repetitions for Different Values of Continuation Probability δ. The Figure Includes the Strategies Which Consists at Least 10% the Population for at Least One Delta Value.

Conclusion

In this study, I investigated the emergence of cooperation and relative success of conditional strategies in a Three Actions Prionser's Dilemma (3PD). Some of the results we obtain provide supporting evidence for the previous results in the literature. For instance, the oscillations between defection and two levels of cooperation were expected in the light of previous studies (Wahl and Nowak, 1999b; Nowak and Sigmund, 1989; Bendor and Swistak, 1995; Imhof et al., 2005; van Veelen et al., 2012; García and van Veelen, 2016; van Veelen et al., 2012). Moreover, the initial strategy is indeed decisive for the success of a conditional strategy (Wahl and Nowak, 1999a,b).

The results suggest that, for a conditionally cooperative strategy to be successful, the initial moves should be in accordance with the action where a strategy is most successful against itself. The most successful types considering all possible continuation probabilities are: selfish and relatively selfish types that start with defection(L); hump-shaped and conditional cooperator type which has the conditional response LMM that start with M; and all-or-nothing and perfect-conditional-cooperator types that start with H. Those types outperform other types who have the same conditional strategy but a different initial move. Those results suggest that strategies with a non-aligned initial move fail to reach the interaction cycle where they would profit most.

A particularly surprising result concerns hump-shaped contributors. Those types are often observed in experiments in which conditional preferences are elicited. They are indeed the most common types after conditional cooperators and selfish types in those experiments. It is hard to rationalize this kind of strategy which can be counter-intuitive. At a first glance as they would fail fully to exploit others while not being able to cooperate at a maximum level, but rather stuck in a medium level of cooperation. However the results suggest that as they are able to exploit mistakes made by their opponents better than the cooperative types and they do relatively better than non-cooperative types, it gives a relative advantage where the continuation probability is moderate. If we also consider the case where continuation probability changes over time, we can expect those types to do relatively better than the others. Our setup might be misleading though; since we have three levels, a monotonic increase or a monotonic decrease is not possible around the intermediate cooperation. What should one expect if there were more levels of cooperation? Possibly the answer depends on the structure of mistakes: If we assume mistaken moves to similar actions are more likely, then mistaken moves to actions that are far from the outcome of the response function,and then we might expect those monotonic increments and decreases. Due to computational complexities of this expansion creat, we seek for further research to confirm this hypothesis.

Finally, these results might provide some explanation about the heterogeneity of conditional strategies we observe in experiments. In our setting, different type of strategies arise and different continuation probabilities: selfish types when δ is small, perfect-conditional-cooperators and all-or-none type of conditional cooperators when δ is high and hump-shaped and imperfect conditional cooperators when delta is in-between. Though it is possibly a strong claim that those conditional preferences are direct consequences of evolution, their success in different continuation probabilities are evident. Therefore mixing individuals with different histories, either at a cultural sense or at an evolutionary sense, might result in such heterogeneity.

Appendix

Type Definitions

	denotion	classification		denotion	classification
0	L-LLL	selfish	41	M-MMH	conditional
1	L-LLM	conditional	42	M-MHL	humped
2	L-LLH	conditional	43	M-MHM	humped
3	L-LML	humped	44	M-MHH	conditional
4	L-LMM	conditional	45	M-HLL	other
5	L-LMH	perf-conditional	46	M-HLM	other
6	L-LHL	humped	47	M-HLH	other
7	L-LHM	humped	48	M-HML	other
8	L-LHH	conditional	49	M-HMM	other
9	L-MLL	other	50	M-HMH	other
10	L-MLM	other	51	M-HHL	other
11	L-MLH	other	52	M-HHM	unconditional
12	L-MML	other	53	M-HHH	unconditional
13	L-MMM	unconditional	54	H-LLL	selfish
14	L-MMH	conditional	55	H-LLM	conditional
15	L-MHL	humped	56	H-LLH	conditional
16	L-MHM	humped	57	H-LML	humped
17	L-MHH	conditional	58	H-LMM	conditional
18	L-HLL	other	59	H-LMH	perf-conditional
19	L-HLM	other	60	H-LHL	humped
20	L-HLH	other	61	H-LHM	humped
21	L-HML	other	62	H-LHH	conditional
22	L-HMM	other	63	H-MLL	other
23	L-HMH	other	64	H-MLM	other
24	L-HHL	other	65	H-MLH	other
25	L-HHM	unconditional	66	H-MML	other
26	L-HHH	unconditional	67	H-MMM	unconditional
27	M-LLL	selfish	68	H-MMH	conditional
28	M-LLM	conditional	69	H-MHL	humped
29	M-LLH	conditional	70	H-MHM	humped
30	M-LML	humped	71	H-MHH	conditional
31	M-LMM	conditional	72	H-HLL	other
32	M-LMH	perf-conditional	73	H-HLM	other
33	M-LHL	humped	74	H-HLH	other
34	M-LHM	humped	75	H-HML	other
35	M-LHH	conditional	76	H-HMM	other
36	M-MLL	other	77	H-HMH	other
37	M-MLM	other	78	H-HHL	other
38	M-MLH	other	79	H-HHM	unconditional
39	M-MML	other	80	H-HHH	unconditional
40	M-MMM	unconditional			

Table 4: All Possible Types and Their Classifications

Additional Figures

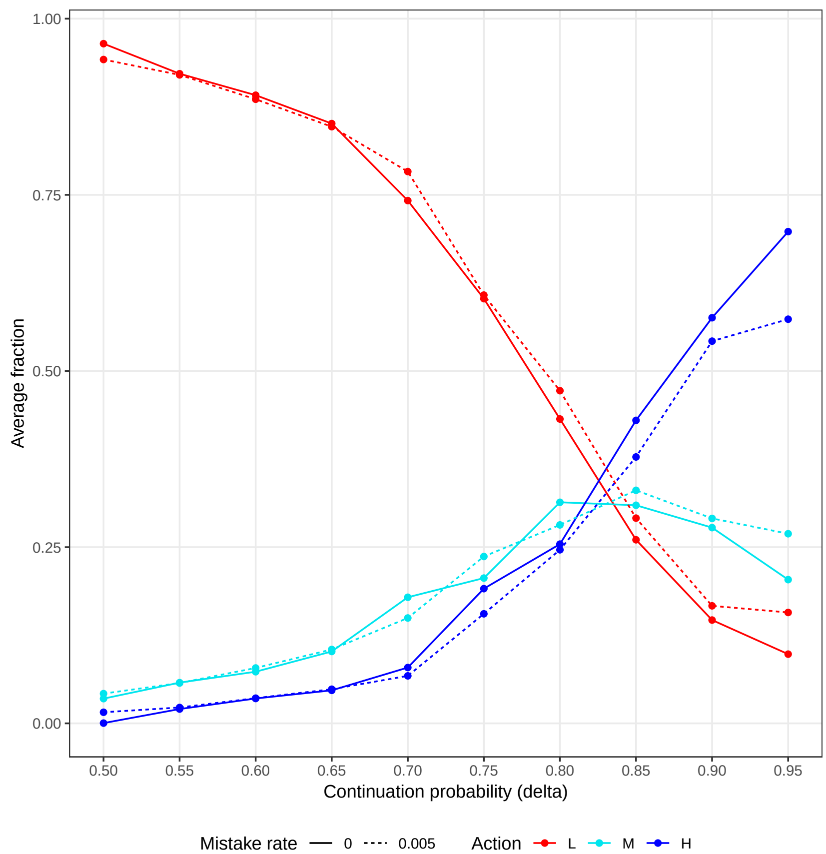

Figure 6: Comparison of Actions with and without mistakes.

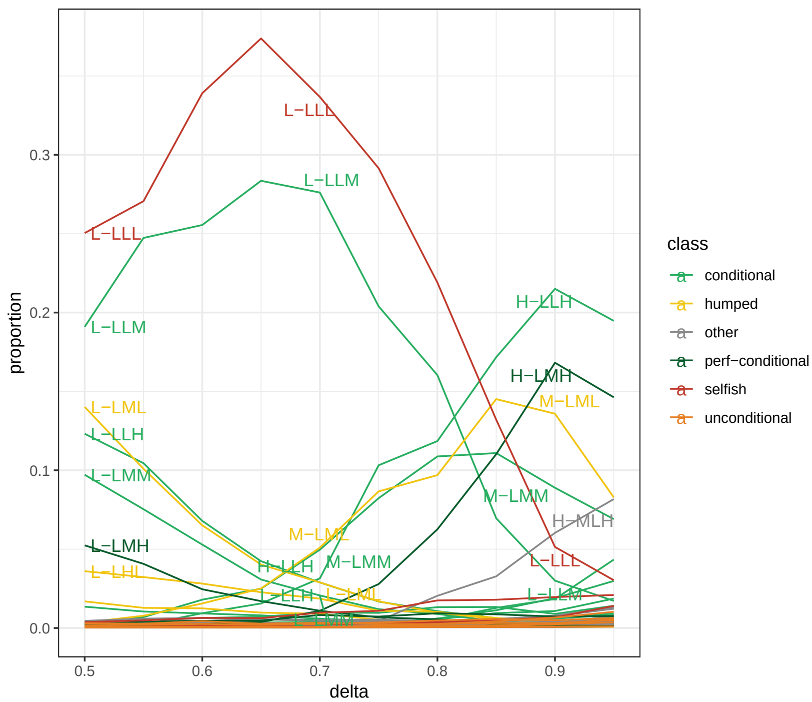

Figure 7: All types' performance for different continuation probabilities.

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