

[Giangiacomo Bravo](#) (2008)

Imitation and Cooperation in Different Helping Games

Journal of Artificial Societies and Social Simulation vol. 11, no. 1 8

<<http://jasss.soc.surrey.ac.uk/11/1/8.html>>

For information about citing this article, click [here](#)

Received: 11-Jul-2007 Accepted: 07-Dec-2007 Published: 31-Jan-2008



Abstract

The relation between imitation and cooperation in evolutionary settings presents complex aspects. From one hand, in any environment where egoists are favored over cooperators by selection processes, imitation should lead to a further spreading of the former ones due to the combined processes of individual selection and replication of successful behaviors. On the other hand, if cooperators succeed in forming clusters of mutual helping individuals, imitation may have a positive effect on cooperation by further reproducing this locally dominant behavior. This paper explores the relationship between imitation and cooperation by mean of a simulation model based on two different Helping games. Our model shows that different imitation mechanisms can favor the spreading of cooperation under a wide range of conditions. Moreover, the interplay of imitation and other factors — e.g. the possibility of performing 'conditional associations' strategies — can further foster the success of cooperative agents.

Keywords:

Imitation, Evolution of Cooperation, Helping Game, Indirect Reciprocity



Introduction

1.1

Cooperation is a crucial factor in many biological systems, including human societies. However, the achievement of cooperation represents a dilemma both at the individual level and for the evolutionary theory. According to game theory, cooperation is not an individually rational strategy in social dilemma situations (e.g. Prisoner's dilemma games, Public-good games, etc.). Similarly, evolutionary processes should negatively select any cooperative organism willing to pay a cost in order to offer a benefit to a different organism. Nevertheless, cooperation is widespread in nature and represents probably a crucial factor in the evolutionary history of Earth ([Hammerstein 2003](#); [Margulis 1998](#); [Nowak 2006](#)).

1.2

Experimental studies, as well as day-to-day experience, show that levels of cooperation well below the theoretical expectations are common among human beings in social dilemma situations ([Ahn et al. 2003](#); [Berg et al. 1995](#); [Fehr and Fischbacher 2003](#); [Fehr and Gächter 2002](#); [Gintis et al. 2003](#); [Isaac and Walker 1988](#); [Ostrom et al. 1992](#); [Rabin 1993](#); [Seinen and Schram 2006](#)). A vast number of different mechanism have been advanced in order to explain the discrepancies between the theory and the empirical results (e.g. [Alexander 1987](#); [Axelrod 1984](#); [Nowak and Sigmund 2005](#); [Sober and Wilson 1998](#); [Trivers 1971](#)). Nevertheless, the aim of this paper is not to present a review of cooperation enhancing mechanisms, but to investigate the relationship between cooperation and another typical human attitude: imitation.

1.3

While social learning and some forms of cultural transmission are common among many animal genera (e.g. [Rendell and Whitehead 2001](#); [Whiten 2000](#); [Zentall and Galef 1988](#)), "true imitation" — i.e. the capacity of learning a given behavior directly by observing the same behavior performed by another individual — seems to be highly developed only in humans and it may represent a necessary condition for the cumulative cultural evolution processes typical of our species ([Richerson and Boyd 2005](#) 108–111). On the other hand, humans also show unusual levels of cooperation among genetically unrelated individuals ([Fehr and Fischbacher 2003](#); [Trivers 1985](#)). The two "anomalies" are probably linked, in the sense that a long process of

gene–culture coevolution endowed humans both with the ability to build complex cultures and with a set of innate predispositions allowing cooperation in groups larger than what is common in other primates ([Richerson and Boyd 2005](#)).

1.4

At a closer look, the relation between imitation and cooperation is still far from being understood. On one hand, in any environment where the evolutionary processes favor egoists over cooperators, imitation should lead to a further spreading of the former ones due to the combined processes of individual selection and replication of successful behaviors. On the other, if cooperators succeed in forming clusters of mutually helping individuals (e.g. [Epstein 1998](#)), imitation may have a positive effect on cooperation by further reproducing this locally dominant behavior. Moreover, imitation is often "biased", i.e. individuals do not choose at random the behaviors to imitate, but tend to copy those that are more common in their social group or/and the ones that led other individuals to achieve higher payoffs ([Richerson and Boyd 2005](#), 120–126). This paper explores the relationship between imitation and cooperation by means of a simulation model based on two variants of the Helping game (also known as Indirect reciprocity game) (see [Nowak and Sigmund 1998](#), 2005; [Seinen and Schram 2006](#)). Our model shows that different imitation mechanisms can favor the maintaining and even the spreading of cooperation under a wide range of conditions. Moreover, imitation can easily combine with other factors, e.g. the possibility of performing "conditional association" strategies (Joyce et al., 2006), in further fostering the success of cooperative agents.

1.5

This paper is organized as follows: section 2 details the problem, section 3 presents the model, section 4 displays the results, while section 5 discusses them.



Two helping games

2.1

In a Helping game (hereafter HG) players are divided in donors and recipients. Donors choose whether to give or not a positive benefit b (i.e. to help) to the recipients by paying a cost $c > 0$. If each donor has just one recipient and the players play simultaneously in both roles, the payoff matrix takes the form

$$\begin{array}{cc} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \left(\begin{array}{cc} b - c & -c \\ b & 0 \end{array} \right) \end{array}$$

where C (cooperate) means to help the other player while D (defect) means not to help him/her. The game is hence analogous to a Prisoner's dilemma (see [Seinen and Schram 2006](#)).

2.2

When there is more than one recipient for each donor, a crucial difference regarding the cost of helping emerges: either the donor pays the cost c for each recipient he/she helps or he/she pays c only once per round, independently from the recipient number. Since the first case corresponds to privately helping one by one each recipient, while the second one is more similar to a public good provision, from now on we will label the former game *private* HG and the latter *public* HG. It is clear that the two games correspond to quite different interaction situations. A real life example of private HG is sharing food with other individuals (e.g. in human hunter–gatherer groups). An example of public HG is alerting others of an incoming danger at a risk for themselves (e.g. in animal colonies when sentinels scream to alert other colony members when a predator is approaching).

2.3

In order to better formalize the problem, let us imagine a population of agents playing the private HG. Each agent is characterized by a strategy, C or D, and is linked with k other agents: the neighbors. In each round, agents act following their own strategies. Agents playing C always help their k neighbors, i.e. they bear the cost kc in order to offer a benefit b to all other agents in their neighborhood. Agents playing D never help. The round payoff for a cooperator is $P_C = n_C b - kc$, where $n_C \leq k$ is the number of cooperators in its neighborhood. The payoff for a defector is simply $P_D = n_D b$, where $n_D \leq k$ is the number of cooperative players in its neighborhood. Solving for n_C , we have that $P_C > P_D$ when

$$n_c > n_d + k \frac{c}{b} \quad (1)$$

which implies that cooperators can have higher payoff than defectors only when they have more cooperative neighbors than the defectors, plus a constant term given by the neighborhood dimension times the cost–benefit ratio.

2.4

In the public HG, agents play the same game, with the only difference that the cost of helping is paid just once in each round. Now the cooperator payoff is simply $P_C = n_c b - c$ and the (1) turns into

$$n_c > n_d + \frac{c}{b} \quad (2)$$

which also implies $n_c > n_d$, but is less restrictive than the former condition.

2.5

Given the inequalities (1) and (2), it is clear that, in both games, cooperators will earn lower payoffs than defectors when they meet other players at random. More generally, the probability of having a cooperator as neighbor represents a crucial factor in determining the outcome of the game. Neither when cooperators and defectors are equally distributed in the population and meet at random nor when cooperators have, on average, less cooperative neighbors than defectors the former ones have the possibility of making a better living than the latter ones. When those conditions hold, if some payoff–based selection mechanism exists, they will inevitably lead to the disappearing of cooperators (see [Ohtsuki et al. 2006](#)).

2.6

On the other hand, different non–random coupling mechanisms can favor a grouping of cooperators able to support their survival and, eventually, their spreading in the system (e.g. [Epstein 1998](#); [Nowak and May 1992](#); [Németh and Takács 2007](#)). One of the simplest mechanism is to allow cooperators to move to another location when unsatisfied with their neighbor(s). For instance, a recent paper argues indeed that a strategy called MOTH, which urges agents to leave the partners who defect and to remain close to the partners who cooperate, is slightly more successful than Tit–for–Tat in an Axelrod–style computer tournament and can hence represent a non–random sorting force able to favor the spreading of cooperation ([Joyce et al. 2006](#)).

2.7

Another possibility for cooperators to have more C neighbors than defectors is linked to imitation. Any plausible mechanism making cooperators more likely to be imitated than defectors will lead to the creations of cooperator–dominant neighborhoods. The problem is that actual imitation mechanisms are usually supposed to cause the imitation of behaviors leading to a greater success or, at least, of the behaviors that are most common in a given population ([Richerson and Boyd 2005](#)). However, when cooperators, by chance or because of purposeful move, arrange in clusters they may rise higher payoff than defectors and/or become a local majority. Under those conditions, cooperators become the target of imitation and imitation itself turns into an active force in further favoring the spreading of C strategies.

2.8

Finally, it is worth noting that, unlike in the private HG where $b > c$ is a necessary condition for cooperators to earn more than defectors, in the public HG this is no longer true when the difference $(n_c - n_d)$ is sufficiently high. Posing $\delta = n_c - n_d$, the necessary condition for $P_C > P_D$ is $b > c/\delta$, an inequality implying that for values of δ greater than one the cost of helping needs not to be greater than its benefit in order to make cooperators better off than defectors.



The model

3.1

In our model, n agents interact for t rounds on a regular lattice surface in the form of a torus generated by a square having a 32 cell side (i.e. containing 1024 cells in total). The model has been implemented using Netlogo 3.1 ([Wilensky 1999](#)) (see [the accompanying material](#) for a description of the code). At the beginning of each simulation run, agents are randomly distributed in the space. In each round, first agents help (or not) their neighbors, depending on their strategies. For all the experimental conditions^[1], we used a Moore neighborhood formed by the 8 surrounding cells of a given agent. Then payoffs are calculated and each agent compares its success with the mean one of other agents acting in its neighborhood. The success is measured as the payoff earned by agents either in all the previous rounds (TP = true, where TP means "total payoff") or in the last round only (TP = false). If an agent success is less

than the average one of its neighborhood, it gets "unsatisfied" and, depending on the experimental condition, either it explores new strategies by imitating its neighbors or it moves to another location.

3.2

Since imitation can take a vast number of different forms, we relied on the anthropological literature in order to receive some insight about the actual mechanism(s) employed by our species. It turned out that the two most common imitation mechanisms are "imitate the majority" and "imitate the successful". Those "fast and frugal" heuristics ([Gigerenzer and Goldstein 1996](#)) are useful for learning the right behavior in a complex and variable environment and represent a probable outcome of human gene–culture coevolutionary process ([Richerson and Boyd 2005](#)). In our model, all unsatisfied agents will hence imitate their neighbors by updating their strategies following one of those mechanisms. More specifically:

- i. imitate the majority, i.e. unsatisfied agents imitate the strategy that is most common in their neighborhood (henceforth *M condition*);
- ii. imitate the successful
 - a. unsatisfied agents imitate the strategy that *on average* led to the highest payoff in their neighborhood (henceforth *S condition*);
 - b. unsatisfied agents imitate the strategy of the most successful agent in their neighborhood (henceforth *MS condition*).

3.3

Notice that the simplest of the possible imitation mechanisms, where *all* agents (i.e. both unsatisfied and satisfied ones) imitate the most common strategy in their neighborhood, is not interesting for our purposes since the outcome is not dependent on the payoffs earned, but only on the initial proportion of cooperators and defectors. This mechanism will be therefore no longer discussed here.

3.4

The M condition emulates the "frequency–dependent bias" that makes humans prone to imitate the most common behavior in a given population or group ([Richerson and Boyd 2005](#), 120–124). Unsatisfied agents first check whether their own strategy is the most common in their neighborhood. If this is not the case, they change it by imitating the majority strategy.

3.5

The S and MS conditions are two declination of the "model–based bias" that makes humans prone to imitate specific individuals used as "models". Most times, this imitation bias results in the spreading of the behaviors of successful individuals ([Richerson and Boyd 2005](#), 124–126). The difference between the S and the MS condition is that, in the former, the success strategy is the one that *on average* achieves the highest payoff in the neighborhood; in the latter, unsatisfied agents imitate *the single agent* earning the highest payoff in the neighborhood (when more than one agent earn the highest payoff, they choose at random among them).

3.6

Besides imitation, in the move conditions agents have the further possibility of moving to another location when unsatisfied. Each agent possesses a random character $m \in (0,1)$ (uniform distribution) that represents its propensity to move^[2]; m is defined at the beginning of the simulation and remains constant through the whole run. In each round, after the helping stage, unsatisfied agents first decide (depending on m) whether to move to a new location or to remain in the present one.^[3] If they move, they randomly choose a new location among the neighbor cells. If the target location is occupied, they remain in the current one. If they decide not to move, they may change their strategy according to the existing imitation rule.

3.7

Since the possibility of moving of the agents obviously depends on n , we will run the simulation exploring two different cases: $n = 342$, i.e. about 1/3 of the cells are occupied by agents, and $n = 612$, i.e. about 3/5 of the cells are occupied. Notice that exceedingly crowded cases cause the move conditions to approximate the equivalent no–move ones, since the possibilities of moving rapidly become limited when n approaches 1024.

Table 1: Overview of experimental conditions for both the public and the private HG

Condition Parameters

M	$n = 1024, t = 250, TP \in \{true, false\}, b \in \{2, 4, 8, 12, 16\}, c = 1$
S	$n = 1024, t = 250, TP \in \{true, false\}, b \in \{2, 4, 8, 12, 16\}, c = 1$
MS	$n = 1024, t = 250, TP \in \{true, false\}, b \in \{2, 4, 8, 12, 16\}, c = 1$
M–move	$n \in \{342, 612\}, t = 2500, TP \in \{true, false\}, b \in \{0.9, 2, 4, 8, 12, 16\}, c = 1$
S–move	$n \in \{342, 612\}, t = 2500, TP \in \{true, false\}, b \in \{0.9, 2, 4, 8, 12,$

16}, $c = 1$
MS-move $n \in \{342, 612\}$, $t = 2500$, $TP \in \{true, false\}$, $b \in \{0.9, 2, 4, 8, 12, 16\}$, $c = 1$

3.8

The M, MS and S imitation mechanisms will first be explored in a no-move condition, then the possibility of moving will be introduced. Table 1 gives an overview of the parameter setting for all the above experimental conditions. Due to the number of stochastic elements in the simulation, we will run 30 replications for each parameter configuration of each experimental condition and consider their average results. The standard indicator that will be compared across the conditions is the final proportion of cooperators in the model.

Results

No-move conditions

3.9

In the private HG, only a few of the MS conditions led to the spreading of cooperation among agents (Table 2). This result occurs for high levels of b when $TP = false$, but also for medium ones when $TP = true$. Increasing b generally permits to achieve higher final cooperator proportions, however this effect is weaker than the one due to the changing of the imitation conditions. Similarly, considering the total payoffs earned leads to somewhat higher cooperation, but only weakly.

3.10

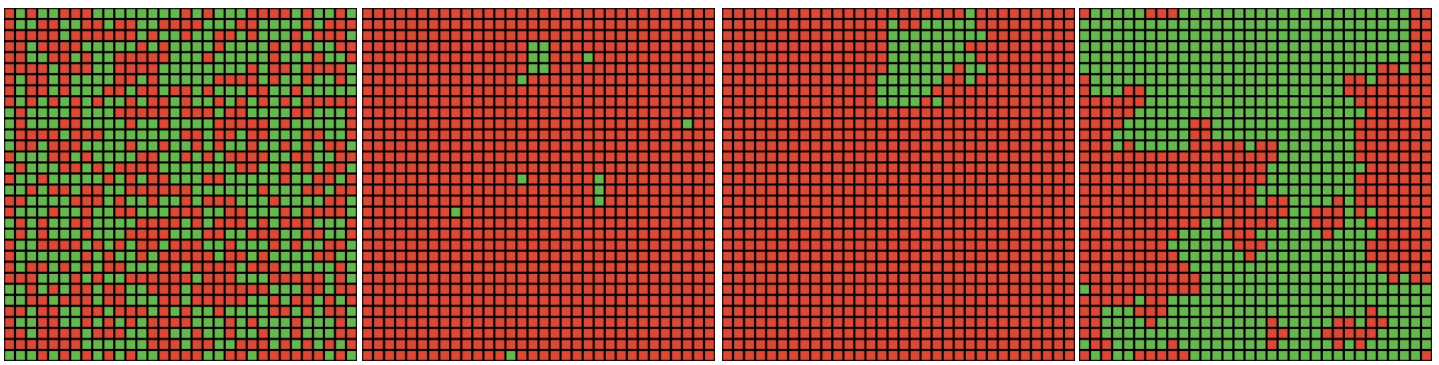
The effect due to the varying of the imitation condition is much stronger. None of the considered parameter configurations permit the achievement of high cooperation level in the system in both the M and S conditions. On the contrary, cooperation spreads in the MS condition under many of the analyzed parameter configurations. Notwithstanding cooperators *on average* earn lower payoffs than defectors, they also achieve the absolute highest earnings. This result may be counter-intuitive, but a short description of the dynamics of a typical run under the MS condition will make it easier to understand. In the very first rounds of the game, the defectors exploit the many unorganized cooperators and earn the highest payoffs. They are consequently imitated by the majority of the other agents up to a point where only a few small clusters of cooperators resist in the system (Figure 1a-c).

Table 2: Final cooperator proportion for the private HG, no-move conditions. Proportions above 0.5 are in bold

Condition	TP	b					
			2	4	8	12	16
M	false	Mean	0.00576	0.00368	0.01556	0.01859	0.03809
		Std. dev.	0.00770	0.00794	0.00817	0.01293	0.01053
	true	Mean	0.00277	0.00257	0.01911	0.03919	0.05674
		Std. dev.	0.00711	0.00826	0.01116	0.01300	0.01746
MS	false	Mean	0.00000	0.15319	0.89922	0.95589	0.95234
		Std. dev.	0.00000	0.25793	0.01545	0.01084	0.01156
	true	Mean	0.00000	0.64160	0.96048	0.97936	0.98005
		Std. dev.	0.00000	0.36037	0.01147	0.00681	0.00789
S	false	Mean	0.00000	0.00462	0.07725	0.14281	0.17227
		Std. dev.	0.00000	0.00480	0.01635	0.03213	0.02488
	true	Mean	0.00000	0.00417	0.08086	0.13210	0.17806
		Std. dev.	0.00000	0.00491	0.02310	0.02762	0.02237

3.11

At this point, most of the defector payoffs are reduced to zero, while the few cooperators that still resist start to be better off. From now on, the MS imitation mechanism favors cooperation that starts spreading in the system (Figure 1d) up to a point where only few small clusters of defectors resist. The system is now in equilibrium and does no longer change until the final round. The full sequence of the cooperation dynamics in the MS condition takes a form somewhat similar to a "checked" ("✓") symbol (see also Figures 2 and 3).



a. $t=0$ (start)

b. $t=1$

c. $t=5$

d. $t=20$

Figure 1. Spatial distribution of cooperators (green) and defectors (red) in a typical run of the MS no-move model for the private HG with TP = true and $b = 4$

3.12

The results for the public HG are similar to the ones above, even if cooperation is somewhat higher for all conditions. In the MS condition all runs with $b \geq 2$ follow a dynamic similar to the one depicted above and end with an overwhelming majority of cooperators. On the other hand, either when TP = true or when TP = false and b is high the M and S conditions also show important numbers (though not the majority) of cooperators. The simulations hence confirm the intuitive idea, also displayed by the inequalities (1) and (2), that it is easier to provide a single public good than many separate private goods for the same number of actors. However, this effect is not strong and other factors, like the imitation condition, can easily overwhelm it.

Table 3: Final cooperator proportion for the public HG, no-move conditions. Proportions above 0.5 are in bold

		b					
Condition	TP		2	4	8	12	16
M	false	Mean	0.06725	0.10119	0.13880	0.13314	0.14290
		Std. dev.	0.03463	0.05157	0.05048	0.04727	0.05253
	true	Mean	0.11789	0.16452	0.17847	0.19551	0.19788
		Std. dev.	0.06455	0.08247	0.08358	0.09007	0.08598
MS	false	Mean	0.95160	0.95339	0.95671	0.95540	0.95576
		Std. dev.	0.01169	0.01147	0.01227	0.01258	0.00961
	true	Mean	0.98203	0.98926	0.99010	0.99095	0.98952
		Std. dev.	0.00821	0.00519	0.00550	0.00448	0.00590
S	false	Mean	0.09382	0.14421	0.18190	0.17142	0.18431
		Std. dev.	0.02816	0.03562	0.03021	0.03341	0.03768
	true	Mean	0.17777	0.24294	0.25658	0.28145	0.28011
		Std. dev.	0.02909	0.02533	0.03275	0.02501	0.02249

Move conditions

3.13

As a whole, the introduction of the possibility to move strongly increases cooperation. In the private HG simulations with $n = 342$, all the conditions with $b > 2$ led to an overwhelming majority of cooperators in the final round (Table 4). As above, cooperation is higher in the MS imitation condition, where most of the runs end with the fixation of cooperators. However, cooperation is widespread also in the M and the S conditions.

Table 4: Final cooperator proportion for the private HG, move conditions, $n = 342$. Proportions above 0.5 are in bold

		b					
Condition	TP		2	4	8	12	16
M	false	Mean	0.08099	0.91501	0.98782	0.99561	0.99776
		Std. dev.	0.17187	0.05504	0.01449	0.00961	0.00618
	true	Mean	0.06891	0.88090	0.98158	0.99357	0.99951
		Std. dev.	0.14708	0.17465	0.01995	0.01068	0.00173
MS	false	Mean	0.49318	0.99981	0.99990	1.00000	1.00000
		Std. dev.	0.50174	0.00107	0.00053	0.00000	0.00000

S	true	Mean	0.62125	1.00000	1.00000	1.00000	1.00000
		Std. dev.	0.48100	0.00000	0.00000	0.00000	0.00000
	false	Mean	0.02710	0.70302	0.94483	0.98421	0.98480
		Std. dev.	0.06981	0.13869	0.04424	0.02592	0.02762
	true	Mean	0.01462	0.71550	0.94522	0.98168	0.98704
		Std. dev.	0.05916	0.07877	0.04922	0.02535	0.02289

3.14

When the number of agents increases ($n = 612$), cooperation appears to be somewhat weakened. However, it still remains above the levels of the no-move conditions, especially for the M and S imitation conditions (Table 5). The decrease in cooperation with respect to the $n = 342$ case is due to the fact that many agents are now "trapped" in crowded neighborhoods where moving is difficult or impossible (two agents cannot share the same cell). When moving is not possible only imitation remains as actual option, leading the move conditions closer to the no-move ones. Notice also that, for low values of b , the cooperation proportion is often lower than in the no-move conditions. This is due to the fact that cooperators that try to form small clusters are now "disturbed" by erring defector. The failure of this closure strategy leads in many cases to the fixation of defectors.

Table 5: Final cooperator proportion for the private HG, move conditions, $n = 612$. Proportions above 0.5 are in bold

		<i>b</i>					
Condition	TP		2	4	8	12	16
M	false	Mean	0.00000	0.24031	0.87048	0.91830	0.95114
		Std. dev.	0.00000	0.24223	0.06774	0.04260	0.02475
	true	Mean	0.00000	0.32849	0.86498	0.92565	0.95496
		Std. dev.	0.00000	0.26191	0.05127	0.03852	0.02367
MS	false	Mean	0.06242	0.99907	0.99951	1.00000	1.00000
		Std. dev.	0.23732	0.00334	0.00197	0.00000	0.00000
	true	Mean	0.02947	0.96645	0.99995	0.99989	1.00000
		Std. dev.	0.16108	0.18253	0.00030	0.00060	0.00000
S	false	Mean	0.00000	0.10044	0.46623	0.59248	0.65419
		Std. dev.	0.00000	0.10510	0.06289	0.05600	0.06697
	true	Mean	0.00000	0.12789	0.47162	0.59869	0.65626
		Std. dev.	0.00000	0.11514	0.06707	0.05265	0.05747

3.15

In the public HG, cooperation spreads in nearly all the experimental conditions and, especially for $n = 342$, cooperators often reach fixation (Table 6).

Table 6: Final cooperator proportion for the public HG, move conditions, $n = 342$. Proportions above 0.5 are in bold

		<i>b</i>					
Condition	TP		2	4	8	12	16
M	false	Mean	0.97456	0.98967	0.99786	0.99854	0.99883
		Std. dev.	0.02552	0.01764	0.00434	0.00594	0.00250
	true	Mean	0.97329	0.99435	0.99844	0.99834	0.99786
		Std. dev.	0.02305	0.01053	0.00314	0.00552	0.00334
MS	false	Mean	0.99990	1.00000	1.00000	1.00000	1.00000
		Std. dev.	0.00053	0.00000	0.00000	0.00000	0.00000
	true	Mean	0.99990	1.00000	0.99971	0.99990	1.00000
		Std. dev.	0.00053	0.00000	0.00160	0.00053	0.00000
S	false	Mean	0.95156	0.99016	0.99532	0.99912	0.99834
		Std. dev.	0.04718	0.02158	0.01026	0.00480	0.00588
	true	Mean	0.94815	0.98694	1.00000	0.99513	1.00000
		Std. dev.	0.04526	0.03734	0.00000	0.01391	0.00000

3.16

Even for $n = 612$ all the runs in the M and MS imitation condition end either with an overwhelming majority of cooperators or with their fixation (Table 7). Only in the S condition and for low values of b a bi-stable equilibrium is found between cooperators and defectors. In this case, neither strategy is able to take the lead and agents continuously update their behavior following the unstable conditions of their neighborhood all along the simulation.

Table 7: Final cooperator proportion for the public HG, move conditions, $n = 612$. Proportions above 0.5 are in bold

		<i>b</i>					
Condition	TP		2	4	8	12	16
M	false	Mean	0.89766	0.97108	0.98045	0.97805	0.98540
		Std. dev.	0.05058	0.01131	0.01226	0.02635	0.00952
	true	Mean	0.91078	0.95654	0.97985	0.98469	0.98557
		Std. dev.	0.04115	0.02992	0.01077	0.00890	0.00587
MS	false	Mean	1.00000	1.00000	1.00000	1.00000	1.00000
		Std. dev.	0.00000	0.00000	0.00000	0.00000	0.00000
	true	Mean	0.99978	0.99995	1.00000	0.99951	1.00000
		Std. dev.	0.00093	0.00030	0.00000	0.00239	0.00000
S	false	Mean	0.52734	0.70833	0.80158	0.81547	0.84243
		Std. dev.	0.10689	0.07230	0.06767	0.04215	0.06016
	true	Mean	0.52870	0.69989	0.80681	0.83034	0.83883
		Std. dev.	0.07979	0.08329	0.04705	0.04347	0.05259

Table 8: Final cooperator proportion for the public HG, move conditions, $b = 0.9$. Proportions above 0.5 are in bold

			<i>n</i>	
Condition	TP		342	612
M	false	Mean	0.24366	0.18573
		Std. Dev.	0.35439	0.22386
	true	Mean	0.41043	0.14744
		Std. Dev.	0.34334	0.22619
MS	false	Mean	0.83168	0.96656
		Std. Dev.	0.37833	0.18255
	true	Mean	0.79250	0.96629
		Std. Dev.	0.40327	0.18251
S	false	Mean	0.15838	0.08415
		Std. Dev.	0.22885	0.09860
	true	Mean	0.11862	0.04532
		Std. Dev.	0.18688	0.06621

3.17

Finally, we studied the case $b < c$ in the public HG by re-running all the move conditions with $b = 0.9$ (Table 8). Cooperation actually spreads only in the MS condition, even if an important minority of cooperators resists also in some of the M condition. In the latter case, the average figures presented in Table 8 actually hinder the aggregation of opposite results: some of the runs lead to the fixation of defectors, while others end with a strong majority of cooperators. At the beginning of each run both outcomes are open and the first part of the simulation (50 to 100 rounds) is crucial in determining which one will actually be reached.

3.18

Figure 2 shows the cooperation dynamics in two different runs of the M-move condition with $b = 0.9$ and $n = 342$. At the beginning of both runs cooperation sharply declines. However, in the first case this process continue until defectors reach fixation while in the second one cooperators succeed in forming tight clusters that represent the foundations for the subsequent growth of cooperation.

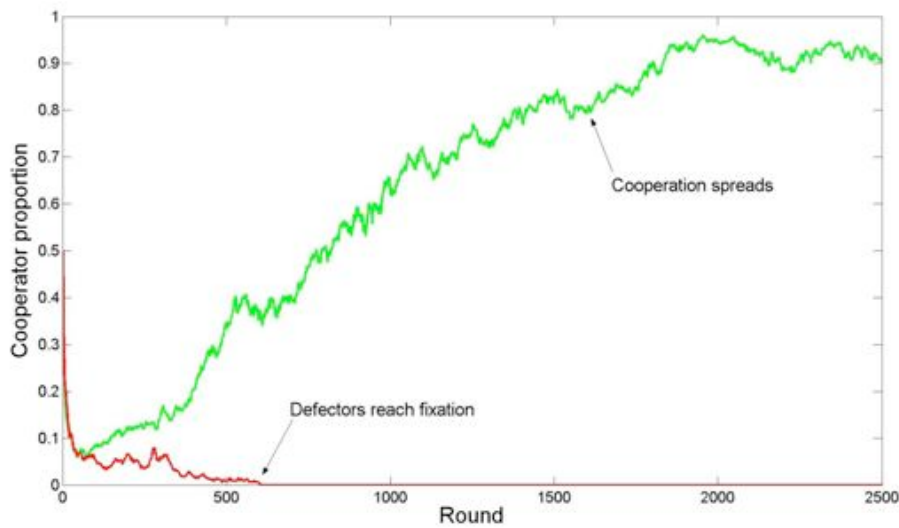


Figure 2. Cooperation dynamics in two different runs of the M-move condition with $b = 0.9$, TP = true and $n = 342$



Discussion

4.1

The simulations show that, in our model, cooperation is possible in many, but not in all the experimental conditions. A number of different factors affect this outcome. First, the cost-benefit ratio, which tends to reduce the difference between n_c and n_d required for the spreading of cooperation. Notice that, according to the inequalities (1) and (2), there is no c / b level sufficient to produce this outcome when $n_c \leq n_d$. This analytical result is supported by the simulations, since in many conditions defectors spread even for very high c / b levels (e.g. $c / b = 16$). On the contrary, there are conditions where low c / b levels (even $c / b = 0.9$ in the public HG, MS-move ones) are sufficient to favor cooperation, thanks to the increased possibility for cooperators of forming closed clusters (and hence of increasing n_c relatively to n_d).

4.2

The result that cooperation has more room in the public HG than in the private one is coherent with the inequalities (1) and (2) and with the fact that, all other things being equal, the cost of cooperation is lower in the public HG. Somewhat more surprising is the magnitude of the effect of the introduction of the move option, which is actually stronger than the effect given by the structure of the game (public vs. private) and, at least partially, than the cost-benefit ratio one. On the other hand, past research showed that "conditional association" (a strategy that make cooperator prone to continue the interaction with other cooperative players, but to leave the defectors) is able to outperform standard conditional cooperation strategies (e.g. simple reciprocity) in Prisoner's dilemma situations (Joyce et al., 2006). Moreover, the move conditions help cooperators in forming tight clusters, a condition which tends to increase n_c and to decrease n_d favoring the growth of cooperation in the system (see Epstein, 1998; Nowak and May, 1992).

4.3

Especially interesting is the strong influence on cooperation of the different imitation conditions. The condition that most favors the spreading of cooperative agents is the MS one, i.e. a mechanism where agents imitate the strategy of their most successful neighbor. This outcome is due to the fact that, given the initial random mixing of agents, in the first rounds of the simulation defectors are always, *on average*, more successful and hence more satisfied than cooperators. In this situation, unsatisfied cooperators tend to imitate defectors because they are more successful in the S condition or because they are more common in the M one (they rapidly become more common since cooperators are more likely to be unsatisfied, and hence to imitate, than defector). On the other hand, a defector has little probability to become one of the *most successful* agents of the game and to remain in that position long enough to become a good imitation target. This happens because defectors surrounded by other defectors earn zero while defectors surrounded by cooperators achieve high payoffs in the early rounds, but their earnings rapidly drop as soon as their neighbors imitate them. Similarly, cooperators surrounded by defectors cannot become an imitation target since their payoffs are very low. On the other hand, cooperators surrounded by cooperators are in the right position to earn high payoffs for a relatively long time. When, by chance, a C agent stands at the core of a cooperator cluster, it may succeed in becoming a strong imitation target under the MS condition. This is exactly what is shown in Figure 1b, where the few remaining cooperators in the small cluster located in the upper part of the plot are actually the most successful agents of the run. Thanks

to the MS imitation mechanism, in the following rounds the unsatisfied defectors located around the cluster start to imitate the successful cooperators producing a rapid spreading of cooperation (Figure 1c–d).

4.4

This dynamic also explains why the differences between $TP = \text{false}$ and $TP = \text{true}$ are usually greater in the MS than in the other imitation conditions. Since defectors can only succeed for one or, at best, for a few rounds before being imitated, all other things equal a longer payoff memory increases the probability that the overall higher payoffs will be earned by a few "lucky" cooperators.

4.5

Crucial for the understanding of the simulation results is the analysis of the relation between n_c and n_d in the different experimental conditions. Given the inequalities (1) and (2), the cooperator proportion should be strictly linked with n_c and n_d or, better, with their difference δ . However, for a number of reasons it is difficult to systematically analyze the effect of this factor.

4.6

First, computing δ makes little sense when $n_c = k$ or $n_d = 0$ since those cases correspond to single-strategy neighborhoods and, hence, to a situation where agents have no different strategies to imitate. A way to overcome this problem is to consider only the δ of agents having at least one neighbor playing a different strategy. From now on, we will hence consider only the δ of agents in mixed neighborhoods.

4.7

Second, the model dynamics are often deeply nonlinear and characterized by short periods of rapid increase/decrease of cooperation followed by periods of equilibrium. Moreover, there is often a time-lag of a few rounds before the changing of the δ values produces a measurable effect on the cooperator proportion. Most of standard statistical tools are hence little appropriate to analyze this relation.

4.8

Third, while the neighborhood dimension in the no move conditions is exactly 8 for all agents, this is no longer true in the move ones, where it obviously depends on n . Given the values of n explored above and assuming a random distribution of agents, on average we have $k = 2.7$ for $n = 342$ and $k = 4.8$ for $n = 612$. However, actual k are higher since agents in empty neighborhoods purposely try to find other agents in order to start new interactions.

4.9

Fourth, besides the condition $\delta > 0$ (which is necessary, but by no means sufficient), there are no realistic values of δ able to guarantee the growth of cooperation in the system independently from the experimental condition. Actually, the specific imitation condition sharply influences the values of δ needed to produce a rise in cooperation. An example will help to better clarify this point. Figure 3 reports the first 60 rounds of a run of the private HG model in the MS no-move condition with $b = 4$ and $TP = \text{true}$ where, after an initial decline of cooperation, the system finally succeed in reaching a stable, highly cooperative equilibrium. In the very first rounds, the cooperator proportion falls rapidly. The average value of δ corresponding to this phase is 0.4. From round 4 on the situation changes dramatically with a strong increase of cooperation. To this second "phase" of the run corresponds an average value of δ of 2.7. After round 30, 3/4 of the population is formed by cooperators and their increase first slows down and then stops around round 50. An average $\delta = 2.1$ corresponds to the slow growth phase, $\delta = 1.6$ to the stabilization one.^[4] The relative values of δ in the four phases of the run confirm the idea that this factor strongly influences the cooperation dynamics of our model.

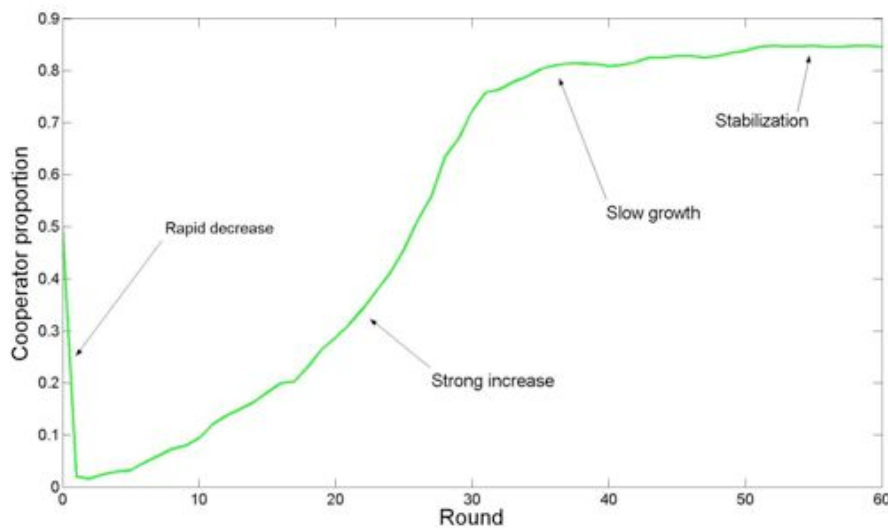


Figure 3. Cooperator proportion in the first 60 rounds of a run of the private HG model, MS no-move condition with $b = 4$ and TP = true

4.10

Let's contrast those results with those produced by a run of the model with the same parameter setting, but in the M no-move condition. Cooperation now dramatically falls in rounds 1–5; it further declines, but at a slower pace, in rounds 6–25 and it subsequently stabilizes in a situation where only a few small cooperator clusters persist. The average δ for the three phases are 1.7, 2.6 and 3.1 respectively.^[5] As in the previous example, the relative values of δ in the three phases are in the right order. However, the value of δ that produces a strong increase of cooperation in the MS condition is similar to the one corresponding to the slow decline phase in the M condition. Also the equilibrium value is much lower in the MS condition than in the M one. In general, we found that the *relative* values of δ have a strong influence on the dynamics of cooperation in all the studied conditions. More precisely, the values of δ corresponding to the increasing cooperation phases *within* a single experimental condition are systematically higher than those corresponding to the equilibrium phases which, in turn, are systematically higher than the ones corresponding to the decreasing cooperation phases. However, this is no longer true *between* the different condition since the absolute figures needed to produce a specific dynamic vary widely from case to case.

4.11

Summarizing, while random distribution of cooperators and defectors in spatial lattices and other graph (see Ohtsuki *et al.*, 2006) tends to produce the decline or the disappearance of the formers, we showed that imitation can instead lead to the spreading of cooperation under a wide range of condition. Coherently with past researches (Epstein 1998; Joyce *et al.* 2006), this process is reinforced by the move option, a conditions that allows cooperators to "choose" their partners, it helps the formation of successful cooperator clusters and hence further reduces the probability that defectors find cooperative neighbors to exploit. Overall, the picture of the relationship between imitation and cooperation given by the simulations is a complex one. Imitation affects cooperation by influencing the probability that cooperators interact with other cooperators, but not all the imitation mechanisms are equally apt to promote this outcome.

4.12

The simulations showed that "imitate the most successful" (MS) is the mechanism that most likely leads to the spreading of cooperative behaviors. Being powerful and easy to use, this mechanism is important in the real world (Richerson and Boyd 2005). It actually represents a "fast and frugal" heuristic able to significantly affect the behavioral choices of people. In many situations, prestige — i.e. the (not so) invisible "aura" that surrounds successful individuals — represents a reliable social proxy for success. Both experiments and field studies suggest that prestige plays an important role in social learning (Richerson and Boyd 2005, 125). Moreover, since this mechanism promotes the diffusion of successful behaviors, it is easy to imagine that natural or cultural selection processes favored its spreading. On the other hand, the S mechanism needs more information in order to be applied in practice. No proxies simple as prestige exist in human societies to indicate the average successful behavior. Though equally adaptive from a theoretical point of view, the S mechanism is hence much more difficult to employ in the real world.

4.13

Another mechanism having strong adaptive qualities is often easy to implement in the real world, i.e. "imitate the majority" (M). Henrich and Boyd (1998) showed that the evolution of a similar conformist bias is favored in slow changing environments and when information about what is the optimal behavior is poor. Besides the fact that the influence of conformism on humans is part of day-to-day experience, a number of classic psychological studies show that

most people tend to conform their views and behaviors to the ones of the majority of others (see [Aroson et al. 2002](#), chapter 8). Since the M mechanism leads, all other things being equal, to lower cooperation than the MS one, the relative balance of the two mechanisms in a given situation should have a strong influence on the possibility of reaching a cooperative outcome. Future researches trying to better understand the interplay of the two mechanisms when they are simultaneously present in a population are hence worth pursuing.



Acknowledgements

The author gratefully acknowledges comments and suggestions from Riccardo Boero, Flaminio Squazzoni and from one anonymous reviewer.



Notes

¹ With the expression “experimental condition” we refer to major changes that affect the decision routines of the agents and/or the structure of the model itself. For instance, the implementation of each different imitation mechanisms represents a single experimental condition. Each experimental condition has been run with different parameter settings, e.g. number of players, costs and benefits of cooperation, etc. (see Table 1 for an overview of the experimental conditions and the parameter settings).

² From a different point of view, m can also represent the propensity of a given agent to continue with its current strategy, resisting the conditioning of other agents by leaving them.

³ Agents in empty neighborhoods are automatically considered unsatisfied and always move.

⁴ A t tests shows that the differences between the phases are significant at the 1% level.

⁵ The differences are also significant at the 1% level



References

AHN TK, Ostrom E, and Walker J (2003) Heterogeneous Preferences and Collective Action. *Public Choice*, 117: 295–314.

ALEXANDER RD (1987) *The Biology of Moral Systems*. New York: Basic Books.

AROSON E, Wilson TD, and Akert RM (2002) *Social Psychology (4th ed.)*. Upper Saddle River: Prentice Hall.

AXELROD R (1984) *The Evolution of Cooperation*. New York: Basic Books.

BERG J, Dickhaut J, and McCabe KA (1995) Trust, Reciprocity and Social History. *Games and Economic Behavior*, 10: 122–142.

EPSTEIN JM (1998) Zones of Cooperation in Demographic Prisoner's Dilemma. *Complexity*, 4, 2: 36–48.

FEHR E and Fischbacher U (2003) The Nature of Human Altruism. *Nature*, 525: 785–791.

FEHR E and Gächter S (2002) Altruistic Punishment in Humans. *Nature*, 415: 137–140.

GIGERENZER G and Goldstein DG (1996) Reasoning the Fast and Frugal Way: Models of Bounded Rationality. *Psychological Review*, 103: 650–669.

GINTIS H, Bowles S, Boyd R, and Fehr E (2003) Explaining Altruistic Behavior in Humans. *Evolution and Human Behavior*, 24: 153–172.

HAMMERSTEIN P, editor (2003) *Genetic and Cultural Evolution of Cooperation*. Cambridge: The MIT Press.

HENRICH J and Boyd R (1998) The Evolution of Conformist Transmission and the Emergence of Between-Group Differences. *Evolution and Human Behavior*, 19: 215–241.

ISAAC MR and Walker J (1988) Communication and Free-Riding Behavior: The Voluntary Contribution Mechanism. *Economic Inquiry*, 26: 51–74.

JOYCE D, Kennison J, Densmore O, Guerin S, Barr S, Charles E, and Thompson NS (2006) My Way or the Highway: a More Naturalistic Model of Altruism Tested in an Iterative Prisoners' Dilemma. *Journal of Artificial Societies and Social Simulation*, 9 (2) 4

MARGULIS L (1998) *The Symbiotic Planet. A New Look at Evolution*. London: Weidenfeld & Nicolson.

NÉMETH A and Takács K (2007) The Evolution of Altruism in Spatially Structured Populations. *Journal of Artificial Societies and Social Simulation*, 10 (3) 4
<http://jasss.soc.surrey.ac.uk/10/3/4.html>.

NOWAK MA (2006) Five Rules for the Evolution of Cooperation. *Science*, 314: 1560–1563.

NOWAK MA and May RM (1992) Evolutionary Games and Spatial Chaos. *Nature*, 359: 826–829.

NOWAK MA and Sigmund K (1998) Evolution of Indirect Reciprocity by Image Scoring. *Nature*, 393: 573–577.

Nowak MA and Sigmund K (2005) Evolution of Indirect Reciprocity. *Nature*, 437: 1291–1298.

OHTSUKI H, Hauert C, Lieberman E, and Nowak MA (2006) A Simple Rule for the Evolution of Cooperation on Graphs and Social Networks. *Nature*, 441: 502–505.

OSTROM E, Walker J, and Gardner R (1992) Covenants With and Without a Sword: Self-Governance Is Possible. *American Political Science Review*, 86: 404–417.

RABIN M (1993) Incorporating Fairness into Game Theory and Economics. *American Economic Review*, 83: 1281–1302.

RENDELL L and Whitehead H (2001) Culture in Wales and Dolphins. *Behavioral & Brain Sciences*, 24: 309–82.

RICHERSON PJ and Boyd R (2005) *Not by Genes Alone: How Culture Transformed Human Evolution*. Chicago: The University of Chicago Press.

SEINEN I and Schram A (2006) Status and Group Norms: Indirect Reciprocity in a Helping Experiment. *European Economic Review*, 50: 581–602.

SOBER E and Wilson DS (1998) *Unto Others: The Evolution and Psychology of Unselfish Behavior*. Cambridge: Harvard University Press.

TRIVERS RL (1971) The Evolution of Reciprocal Altruism. *Quarterly Review of Biology*, 46: 35–57.

TRIVERS RL (1985) *Social Evolution*. Menlo Park: Benjamin Cummings.

WHITEN A (2000) Primate Culture and Social Learning. *Cognitive Science*, 24: 477–508.

WILENSKY U (1999) *Netlogo 3.1*. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. <http://ccl.northwestern.edu/netlogo/>.

ZENTALL T and Galef JBG, editors (1988) *Social Learning: Psychological and Biological Perspectives*. Hillsdale, NJ: Lawrence Erlbaum Associates.

