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Investigating hierarchical class segregation and the use of punishment applied downward in a hierarchy acts as a key aspect to ascertain how dominant and subordinate partners cooperate to achieve mutual profit. In countries with an uneven wealth distribution, this mutual profit may be reduced, especially for the lower socioeconomic classes. In this experiment, we implemented an Iterated Prisoner's Dilemma Game in one such country with a starkly high Gini index, China. We split relatively richer and poorer subjects into separate classes and gave only one the authority to punish the other. When rich subjects could unidirectionally punish poor subjects (as in a segregated society), rich subjects decreased their cooperation effort while punishing poor subjects. When rich and poor subjects, instead, could punish each other in random combinations (as in an integrated society) they decreased defections so they could punish more. In the segregated society model, the punishing classes earned twice as much as the non-punishers. Conversely, in the integrated society model, weak differences in earnings were found, leading to a decrease in inequality. An Agent Based simulation confirmed these results when the interacting agents became thousands rather than the over three hundred human participants. From our research, we conclude that, especially in developing economies, stimulating the wealthier and poorer individuals towards a socioeconomic integration of their cooperative exchanges may ultimately lead to a redistribution of wealth.

cooperation | punishment | Iterated Prisoner's Dilemma game | socioeconomic class segregation | Agent Based Modelling

Introduction

The nature of social relationships in which cooperative or defective individuals typically engage is constantly ruled by the asymmetric exercise of power found in nature and within structured human hierarchies (1-7). When specifically accounting for these individual characteristics and the inherent differential power of the tested subjects, we know that within-group inequalities in resource holdings affect individuals' cooperation (8-12). Therefore, when inter-hierarchical interactions take place, the exercise of power may lead to an alteration of the initial, hypothetical centrality of the game, with an eventual shift of the strategy of the players (13-17).

Although behavioural economics research has traditionally focussed on the factors that determine the individuals' choices between cooperation and defection, researchers have widened the perspective by including punishment as a further strategy to induce cooperation in repeated social interactions (e.g. 18, 19-21). A number of examples have been found in nature in which several species display punishment providing the individuals with an option to attempt being increasing their own fitness (22), but whether or not this behaviour prompts a higher use of cooperation or, rather, retaliation is still a question open to debate (19, 23-35).

When punishment is a strategy the players can enforce, asymmetric interests may become more apparent in Public Good Games (31, 36-39) and the players' final payoffs may even further differentiate (11, 27, 40). This may be the case especially when social classes are segregated, leaving it largely up to the more powerful partners to impose such a strategy over their less dominant partners.

Socioeconomic class segregation is a relevant character in human societies with a high rate of income inequality (41-43). Modelling the behaviour of individuals coming from such economic constellations allow us to better scrutinise human cooperation at an evolutionary level (44), for example during times when states have not implemented yet thorough wealth redistribution policies (45). For the first time after 12 years, in 2013, the Gini coefficient (measuring income inequality within countries) of the world most populous country of China has become publicly known (46) presenting predictably high levels in the range of 0.53 – 0.55 (47). Top scoring countries like South Africa, Brazil and Nigeria fare at 0.4 - 0.6 Gini levels. More recent data, accessed from possibly biased governmental sources, report that the Gini index in 2015 stood at 0.462 and last year at 0.465 (48).

Although the negative effects of class segregations are well known in these countries, and 77% respondent Chinese citizens declare large concerns in this regard (49, 50), we don't know of any empirical examples in behavioural economics literature and Prisoner's Dilemma Games displaying how to lessen the individuals' disparity in incomes. More general studies that take socioeconomic distinctions into consideration within the social dilemmas' literature also appear to be quite few. Recently Bone and colleagues (51) provided social dilemma game participants with different punishing powers. We chose a different approach. In our experiment, we estimated and accounted for the participants' socioeconomic background as a life history covariate determining their ability to punish or not punish the opponents.

Significance

The discipline of economics has historically looked at the effects of income distribution on overall economic growth, essentially taking the position that while a more equal distribution of income might indeed be a social good, any policy efforts to promote redistribution do exact an overall cost. However, if risk-taking behaviour is deterred by income inequality, this overall cost might become negligible. We empirically model socioeconomic class segregation in a human society with a high rate of income inequality, China. Here, more dominant individuals could exert punishment over less dominant ones. We found that a redistribution of wealth can be attained only when both rich and poor subjects are allowed to punish each other as in an integrated condition.

More specifically, we invited richer and poorer Chinese individuals to play a Prisoners Dilemma Game with a costly punishment option in both a segregated and an integrated condition. Steep differences were found in payoff gains in the segregated condition (rich people playing with poor ones), while no differences were found in the integrated condition (designed and implemented with random socioeconomic matching). To model the effect of punishment realistically, we imposed a simplified and skewed payoff strategy on the players, whereby at a first stage only the dominant and richer players were able to exert punishment on subordinate and poorer players. Later, we allowed for only the poorer subjects to punish the richer ones instead. By doing so, we established two treatments to predict whether such segregated societies in relation to both punishment and socioeconomic status would have influenced changes in the players' preferred strategies and payoff gains versus the third treatment results of an integrated society. We ran an Agent Based model after collecting the human data to confirm some of our hypotheses, namely, to find out the cognitive constraints leading to the choice of certain strategies and whether the behavioural trends were maintained in a simulated environment bearing different population sizes.

Methods

Laboratory experiments

The experiments were performed at Yunnan University of Finance and Economics (Kunming, China) with university students still novel to game theory and behavioural economics tests. Approval was obtained by the university's ethics committee board on the use of human subjects in research and informed consent forms were obtained by all the anonymous participants. The experiments took place during 9 different days of November and December 2014 and of April 2015. The students' age spanned from 18 to 22 and their geographical provenience varied across different parts of China. We tested a total of 348 students (164 males, 184 females). The same subject never took part in more than one experiment and that subjects had not previously participated in other behavioural experiments. Our analyses included 9 experimental sessions with three replicate sessions for each of the three game scenarios.

While sitting in a computer lab, the students were briefed in neutral terms regarding the rules of the Iterated Prisoner's Dilemma Game. The experiment consisted of three different treatments. In each of them, the students were allocated to two different trading classes. In the CDP class, the subjects were free to choose between three strategies: cooperation, defection, and punishment (referred as A, B, and C to the students). In the CD class, they were only allowed to choose between two strategies: cooperation and defection. For simplicity, the exit option to terminate the interaction (52) was not given to the players. The treatments were implemented as following: in T_0 the subjects were assigned randomly to the CDP and CD class; in T_1 richer students were assigned to the CDP class and poorer ones to the CD class; in T_2 (the reverse of T_1) poorer subjects could choose any option amongst CDP while the richer ones could opt only for CD. The treatments comprised a number of subjects so to be counterbalanced: T_0 116 students, T_1 122 students, and T_3 110 students. The students were not informed of the socioeconomic principles which we elected to offer them for the purposes of our research and why their options differed. They were simply informed that one group had the option of employing the extra strategy, namely, punishment.

The purpose of T_1 is to simulate societies often found in developing countries with high Gini coefficients – with China at present providing an extreme example (47). T_2, contrastively, stand out as an unlikely scenario in which poor people can only punish people richer than them. This treatment helps ascertain some degree of causation arising between T_0 and T_1. That is, whether results can be interpreted simply via implementation of the segregation effect or whether the segregation effect combined with the social status influenced the outcome.

The payoff matrix as designated in the diagram below shows the outcome of the round of each game expressed in earned points. Upper and lower case letters indicate the reading order.

player 2

PLAYER 1	Cooperation	Defection
Cooperation	**1, 1** A, a	**-1, 2** B, d
Defection	**2, -1** C, b	**0, 0** D, e
Punishment	**1, -3** E, c	**-1, -2** F, f

We matched the individuals into dyads who had to repeatedly interact at successive rounds. We tallied an average of 82.5 iterated rounds per session and 22.4 interactions per session. During each round of interactions, two participants simultaneously chose between two or three available options (CD or CDP). At the completion of each round, each participant was shown his or her partner's choice together with the total payoff scores. The experimental sessions averaged 38 participants each, with an average duration of each experiment of approximately one hour (unknown to the players, to avoid end-game effects). At the end, each subject received an average payment of ¥ 53.64 Chinese renminbi.

At present in China there is no consistent criterion for assigning scholarships to students from lower income families. Thus, university enrolment offices are not aware of the precise socioeconomic status of their students. To obtain this information, we requested each student to fill an anonymous questionnaire supplying us with this indispensable data before the start of the experiments. From the students' answers, we could assign each subject to the two classes while concomitantly applying the permissible strategies as per our methodology, either CDP or CD, by calculating the results of their answers in real time. In particular, we asked students to provide basic demographic information focussing on their families' income. The list included, how many houses their family owns, how many cars, how many rooms present in their first house, their parents' job type, and whether they have an undergraduate degree (for the full list of questions, see S.I.). From their answers, we calculated a score in order to quantify where they stood along a variable socioeconomic class spectrum. This score was determined as

Y = 2.5 HOUSE# + 2(CAR# + 1)/FAMMEMB# + 2 ((ROOM# + 1) / FAMMEMB#) + 1.5 ((1.5 FATJOB) + MOTJOB) + FATBACDEG + MOTBACDEG

We assigned different weights to these indicators of wealth, based on the common assumption that, for example, the possession of properties weighs more than the possession of cars.

Using the results, we could rank and assign each subject to one of the two classes we created, splitting them according to whether their answers placed them below or above the median of their respective scores.

Informed consent forms were submitted for all subjects in our research. The Yunnan University of Finance and Economics Ethics Committee approved all the experiments utilising human subjects, which, in turn, was carried out in accordance with the approved guidelines.

Agent Based model

Following the lab experiment, we developed a set of Agent Based simulations to compare the simpler behaviour of agents with humans, when the former adopted similar or different strategies than the latter group. Adopting an Agent Based modelling approach, in fact, offers one significant advantage: the experimenters can test different hypotheses pertaining to the cognitive mechanisms needed to perform different behaviours (55). We achieved this result by modifying the behavioural rules and properties characterising the agents and re-running the model to control for the stochasticity affecting each Agent Based model.

As in the segregation treatments of T_1 and T_2, we split the agents into two economic classes (rich and poor) and we assigned a group dependent propensity in adopting a cooperative or defective behaviour. In these cases, we were not investigating the evolution of the group dependent propensity – since it was assigned a priori – nor the interplay between the group dependent propensity and the resulting cooperative or defective behaviour. In another set of simulations, for contrastive purposes, we selected an experimental condition where human subjects are randomly assigned to one of the two economic classes, as in the integration treatment of T_0. The main purpose of this modelling approach was to investigate whether there is an effect in adopting a specific cognitive strategy while being in a condition of segregation or integration.

While playing this type of Iterated Prisoner's Dilemma Game, the agents could adopt one of three possible strategies: a classical Tit-for-Tat strategy, a short-term memory strategy, or an incremental memory strategy with complete retention of all the previous rounds (e.g. 56). In the case of the short memory strategy, we tested two different experimental conditions in which the agents were able to remember the outcomes of a very small number (i.e., 5) or a small number (10) of past rounds. Conversely, in the case of complete knowledge, we adopted an incremental approach where agents were enabled to remember the outcome of all past rounds as they occurred over time.

The agents played according to the same payoff matrix adopted in the experiments with human subjects. In the first scenario, each agent played according to a Tit-for-Tat strategy with the same payoffs matrix 3x2 used in the human experiment (for details, see the description of the algorithm in S.I.). In the short-term memory scenario, agents were equipped with a memory able to store and process only a finite and fixed amount of information; meaning that their memory size did not change over time. The agents were able to remember only the last 10 (or 5) previous rounds with the same partner. Lastly, in the third scenario, the agents were capable of remembering and processing all past rounds with the same partner. In such way the agents build up the most complete knowledge of their opponents over time and in an incremental way (the longer the interaction lasts, the more elements the agents can recall to select the most profitable strategy).

The first hypothesis we decided to test is whether the social status of the individuals affected their propensity to cooperate. In the model, in fact, we gave for granted that such phenomenon exists, due to the results originated from the human experiment. Our assumption was to ascertain if the fact that richer individuals may be more likely to cooperate was due to knowing they could rely on other people with more wealth. Poorer individuals, instead, may be more likely to play safe and defect because their life circumstances generally are more of need (40, 57). For this reason, in the first set of simulations we assigned a probability of $p = 0.7$ to the richer agents to cooperate or to the poorer to defect in the first rounds lacking prior information. Later, we decided to test a set of different hypotheses considering: i) a scenario where there was no difference in belonging to one of the two classes and there was a generalized high propensity to perform defective acts in first rounds (i.e., $p = 0.95$ for all agents) (see 58, 59 for the scientific background which inspired this); and ii) the size of the memory in the short memory condition is 5 rounds instead of 10 rounds. Finally, we replicated the simulations varying the size of the agent population according to naturally occurring social groups (60), to test the robustness of the model (S.I. reports models with 5, 15, 50, 150, 350, and 1000 agents).

For a complete list of the models' parameters, see Table 1 in S.I. The Agent Based models were performed in Netlogo.

Statistical analysis

We acquired two types of empirical data relating to cooperation via z-Tree (61). First, we learnt the proportions of CDP and CD chosen behaviours, and, secondly we discovered the final payoffs gained by each student. These sets of data were analysed by Generalized Linear Mixed Models via R 3.2.4 (62) via the lmerTest package (63).

Validation of the methods

To obtain information about the socioeconomic background of our subjects, we split the students into two classes by calculating 'meta-scores' from their answers to a questionnaire about their families' living conditions and other elements (reported in Supplementary Methods). To validate whether the answers to this questionnaire were representative for ascribing the two student types to their actual socioeconomic classes, we checked whether individuals with higher scores were also those individuals earning more during the experiment. Due to their elevated socioeconomic background, we hypothesised that, in fact, they could have chosen more effective strategies and eventually earned more points (51, 64, 65). This hypothesis was confirmed by our sample, since the single students who earned relatively more within their experimental class division were those coming from a financially better off background ($F_{1,266} = 4.84$, $p = 0.029$) (Figures 1 and 2 in Supplementary Results).

Results

Frequencies of Cooperation, Defection and Punishment

To understand how the players behaved differently as a result of their division into the two CDP and CD classes, we obtained behavioural measures and derived the earnings from them. We used a GLMM with the frequencies of their choices (C, D, or P) as a dependent variable, implementing the split into the two trading classes by treatment as fixed effects while the subjects as random effects. Figure 1 shows the behavioural frequencies the players displayed.

Belonging to either one of the trading classes significantly explained the variation in behavioural strategies ($F_{1,347} = 49.15$, $p < 0.001$). However, the integrated or segregated conditions proved to have no significant effect on the selection of strategies ($F_{2,345} = 0.74, p = 0.47$).

By analysing the differential frequencies of the students' choices, we can infer the impact that punishment had on the players. In T_0, the two classes cooperated at similar levels ($t_{2,9518} = -0.47\, p = 0.63$). However, the 12.4% rate of punishment added to the 68.36% of defection makes up for the defection rate of the CD class not able to punish ($F_{2,9518} = 4.21, p = 0.015$). This indicates that, in the integrated condition, the punishers partly restrain themselves from defecting while punishing. In both T_1 and T_2, conversely, cooperation levels were significantly different across classes ($F_{1,20510} = 266, p < 0.001$) whereas defection levels were not ($F_{2,20505} = 0.226, p = 0.79$). Hence, in both segregation conditions the punishers decreased their cooperation levels when choosing to punish. For a finer representation of what happens during the behavioural exchanges between partners on a time scale, see Figure 3 of S.I.

Players' earnings

One of the driving questions we mined our data for was whether the players earn differently as a result of their disparity in socioeconomic background. Moreover, did their incomes vary due to the condition that only some players were permitted to implement the punishment strategy? The treatments and class separation allowed for exploring such questions (as displayed in Figure 2). In all three different conditions the total earnings achieved by the both classes combined were statistically in the same small range ($T_1 = 101$; $T_2 = 102$; $T_3 = 104$ units + comparable SE's). Thus we can conclude that this manipulation, redistributing the subjects into the two distinct classes, did not cause a sizeable difference in total earnings.

When comparing the treatments, we checked whether in the integrated condition the players earned differently. In this treatment, the players were randomly assigned to the two different classes regardless of their socioeconomic status. The ability to punish the players belonging to the other class made a marginal increase in earnings possible (of 11 points), which proved to be slightly statistically significant ($t_{1,108} = 1{,}999, p = 0.048$). In the two segregation treatments, instead, it is readily apparent how the two classes of players differentiated their earnings. The punishers earned more, almost double as much as the other CD class ($F_{1,229} = 147, p < 0.0001$) regardless of the chosen treatment ($F_{1,229} = 0.064, p = 0.8$).

Agent Based Model

Frequencies of Cooperation, Defection and Punishment

We tested whether agents behaved differently as a result of a combination of factors, namely: i) their division into CDP and CD classes and ensuing ability to either perform only a subset of all possible actions (i.e., the CD class) or all possible actions (i.e., the CDP class); ii) the different cognitive mechanisms involved in selecting to cooperate or to defect; iii) whether there exists a predisposition in actors corresponding to their socioeconomic class when performing a specific behaviour; and, iv) the probability of such a predisposition (the value of p).

Following this, we report results from a population of 350 agents, which is an analogous size to the students involved in the human experiments.

Before running the simulation which most closely resembles the behaviour displayed by the human subjects, we ran prior simulations to test for occurrences of a class-dependent predisposition of rich agents to behave as cooperators or defectors. Additionally, we also ran other simulations to test for the ability of the agents to remember past interactions (see Supplementary Results).

In the final set of simulations which we present here, we tested for a predisposition in all agents towards defection with $p = 0.95$ (for a general predisposition to defect, see 58, 59), exclusively implementing a short term memory strategy. In this case, the number of past round outcomes each agent could remember was fixed at 5.

The simulation shows that defection is the preferred behaviour performed most often by the agents (Figure 3 – for additional analyses about performed behaviour in different parameters settings, see Figures 4-6 in S.I.). In T_0 and T_1 we can see the computerised agents performed behaviours similar to what the human did, with the exception of a generally higher propensity to cooperate. In T_2, though, when agents adopted a Tit-for-Tat strategy, the agents from the class of rich agents selected less punishment; further, when agents adopted a short-term memory strategy, instead (i.e., they were enabled to use outcome information from the preceding 5 interactions), agents from both classes clearly chose to defect more and to cooperate less. Finally, when the agents adopted an incremental memory strategy, there is a small increase in defection performed by agents from both classes (see S.I. for all results). This combination of parameters, (i.e., short term memory strategy and T_2 treatment with a strong propensity to perform defective acts for agents from both classes) led to results remarkably similar to those obtained from the human experiments with Chinese students.

Consequently, the results proved sound when there was no strong variation modifying the group size.

Agents' earnings

For the computerised simulations, as with the human subjects, we also analysed income for the agents in all three treatments.

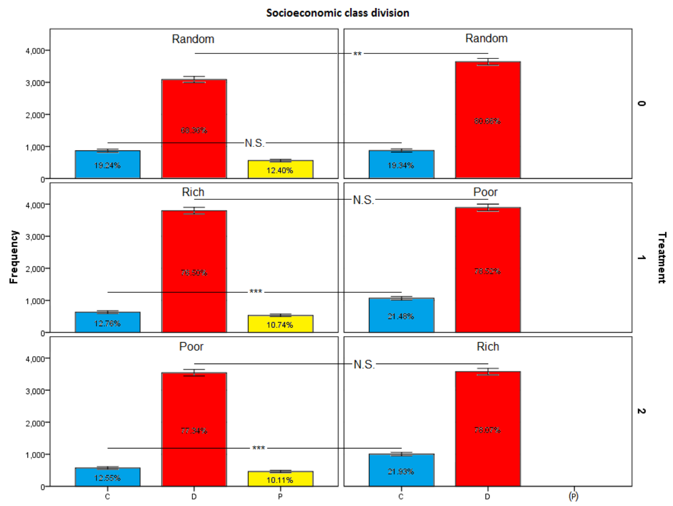

Fig. 1. – Frequencies of Cooperation, Defection and Punishment (C, D, P) across the three treatments. In T_0 the subjects could punish each other by random partner matching, regardless of their socioeconomic class (integrated society model); in T_1 and T the matching was predetermined (segregated society models): in T_1 richer subjects could punish poorer ones, whereas in T_2 poorer could punish richer ones. High levels of defections are found in all treatments, but, in the integrated condition, the punishers limited themselves in defecting while punishing. In both segregation conditions, instead, the punishers decreased their cooperation levels when punishing. ** means p < 0.01, *** means p < 0.001; error bars show standard errors of the means.

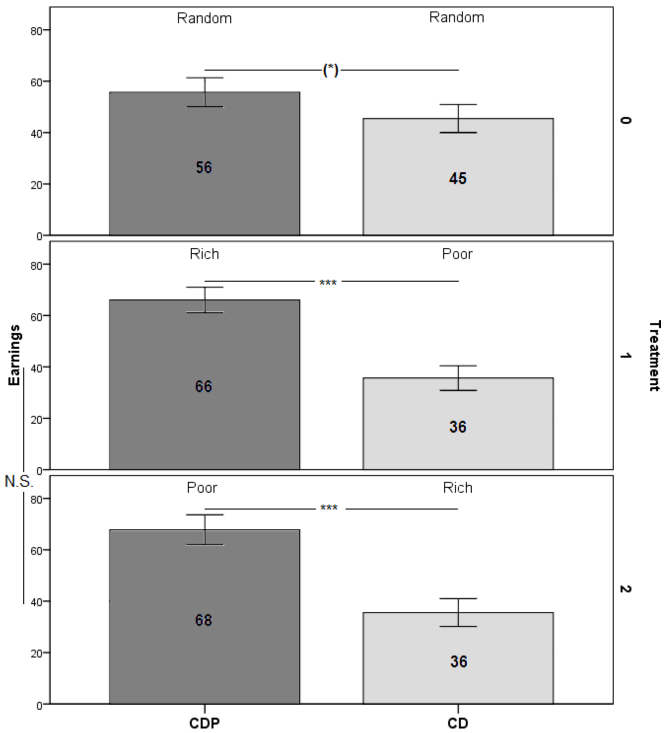

Fig. 2. – Final earnings the subjects obtained from the experiment (measured in Chinese renminbi). In the segregated conditions, the subjects who could punish (CDP) earned double than what those who could not did (CD). (*) means marginally significant, p = 0.048, *** means p < 0.001; error bars show standard errors of the means.

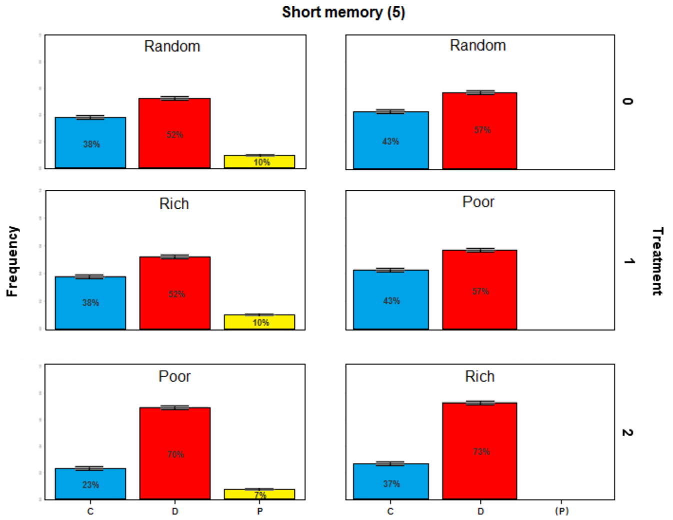

Fig. 3. – Behavioural frequencies shown by the agents in the ABM with a memory size equal to 5 rounds. Defection levels were lower and cooperation was higher compared to the human experiment. The predisposition to defect at first encounter is 95%. N = 350 agents. Error bars show standard error of the mean values with 95% confidence interval.

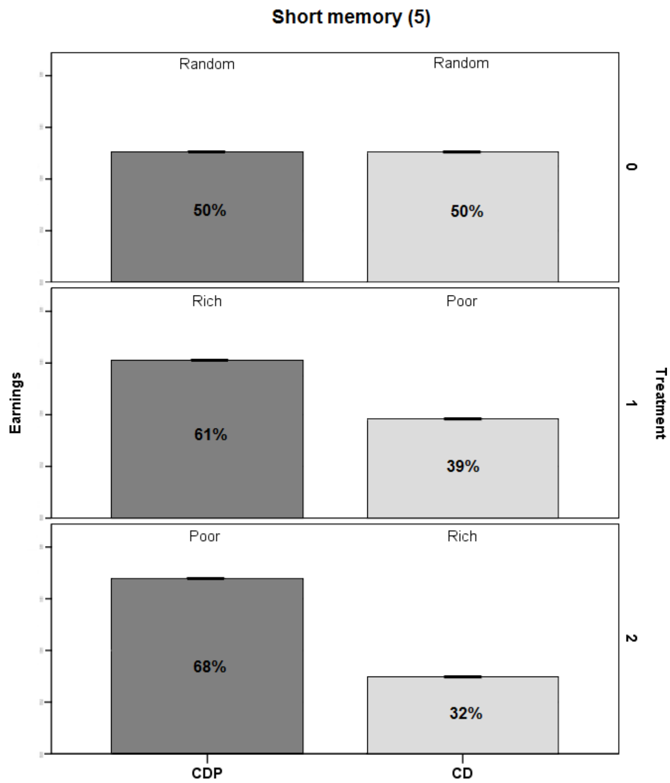

Fig. 4. – ABM final earnings agents obtained from the simulation with a memory size of 5 rounds. In the integration treatment, the agents who could punish (CDP) earned the same amount that those who could not did (CD). In the segregated treatments, those that could punish earned approximately double of those who could not. These results are in line with those of the human experiments. The predisposition to defect in such cases at first encounter is 95%. N = 350 agents. The error bars show standard error rates of the mean values with a 95% confidence interval.

These results are only from the last set of simulations, with a generalized predisposition to defect of $p = 0.95$ and with a short memory size consisting of 5 previous rounds.

In T_0, the agents from both classes tallied the same amount of earnings. In T_1, the richer agents earned double of the poorer agents. In T_2, the richer agents earned more than double the amount of the poorer agents. See Figure 4 below for details. For additional analyses about earning, see Figure 7-9 in S.I.

Discussion

We tested for behavioural changes when relatively richer and poorer individuals were permitted to interact within the context of a Prisoners' Dilemma Game. Selecting the subjects from a country where the distribution of wealth is plainly uneven and in which socioeconomic classes are just as evidently distinct (47, 66), we were interested in examining how this state of socioeconomic segregation alters the anonymous subjects' behaviour and, subsequently, their incomes. In the treatment modelling an integrated society, the subjects could freely trade points across socioeconomic classes. In the models inspired by our notion of still realistic socioeconomic class segregation, the classes were split and permitted, alternatively, to interact from one class to the other. In all treatments the use of punishment was allowed to be carried out by only one class. Comparing the treatments, we could ascertain that the behavioural and monetary differences we eventually found were by and large due to the effect of socioeconomic segregation.

The class division we implemented did not cause a difference in the total earnings gained by all the players. We can therefore say that the players, on average, earned the same amount regardless of whether they interacted in a segregated or integrated socioeconomic condition. In the segregated models, final incomes amounted to a 92% increase in favour of the class which could punish the other one for the human experiment, and, in the computer simulations, a difference of + 90%. The inequality therefore increased after the experiment. However, in the integrated model, the incomes proved to only be modestly dissimilar for the human subjects (+25%) and they turned out the same in the computer simulations. Comparing the behaviours originating in the segregated societies (T_1 with T_2), the amounts of cooperation, defection, and punishment behaviours (and their final payoff gains) of rich and poor individuals did not show any difference. We therefore conclude people and agents from either background do not seem to implement punishment according to what they learned in their different milieus to ultimately gain any further.

By splitting the anonymous players according to their different socioeconomic classes, we brought about behavioural changes in subjects who were not aware of the social status of the other partners (36). These two elements lead us to the conclusion that it is precisely the integration effect that allows for a redistribution of wealth. Firstly, the alternation of encounters of partners with similar or different socioeconomic origins could balance out the earnings and, secondly, the use of intra-class punishment (rich versus rich, and poor versus poor) may well also narrow the gap related to different final payoff earnings. Furthermore, the Agent Based simulations confirmed that the strategy adopted by the Chinese subjects relied on the memory of the five preceding rounds. Finally, that there is a strong individual propensity to defect in the first rounds when no prior information about the partner's behaviour is yet available. The same applies when the simulations are rerun with a smaller and larger number of agents. It is therefore during these initial exchanges that players adjust their strategies to predominantly defect. A prevalence for defection by Chinese subjects is not a novel to our study but rather a feature already noted by other authors (i. e. 53).

By focussing on the ability to punish, an option realistically more frequently opted for downward in the social hierarchy than upward, we showed how disparity in socioeconomic classes does not cause a modification in cooperative behaviours per se. Rather than allowing the subjects to punish personally their partners, a different game could be implemented by giving the authority to a centralized authority or only selected individuals to use second-order punishment – as done in those Public Good Games of Hilbe et al. (32) and Baldassarri and Grossman (31). As it stands, this experiment can be compared to other Iterated Prisoner's Dilemma games in similar anonymous player condition. However, another direction to be investigated could be looking at the different behaviours that may emerge when we inform the subjects about their reciprocal identities concerning their social status. Our results are somewhat different from previous, resonant research conducted elsewhere, which concluded that members of different socioeconomic classes were found cooperating in their own unique ways (64, 67). In these two studies, for instance, people from lower socioeconomic classes plausibly offered less in donation experiments due to their perceived higher relative cost of cooperation, to a certain extent higher than for the wealthy ones. In the Bone et al (51) study, students were given different punishing powers and, as a result, the weaker subjects also wound up investing less. In our case, by contrast, the investments made by the poorer subjects as a class when playing on their own fared at the same levels of the richer ones. Regardless of cultural effects (23, 28, 36, 53, 66, 68, 69), one possible explanation could be that our 'poorer' subjects were relatively better off than the subjects in the studies previously cited from London and New York (51, 64, 67). Access to higher education is, in fact, a relatively recent phenomenon in China and, unlike in the U.K. or U.S., tuition fees are always levied here.

Lastly, it should be noted that the students not able to punish might have been affected in their behaviours by the threat of being punished, regardless of the actual use of punishment employed by their more powerful partners (11, 23).

Through the differential use of punishment, we modelled how a redistribution of wealth can be achieved following some of the principles of the Keynesian approach to a free-market economy (between the states, see 70, 71). In a more base and practical sense, state systems in high Gini-coefficient countries should seek to implement practical measures and act decisively to foster a decrease in the yawning gap in socioeconomic classes. Regardless of its impressive, overall and top line economic development, China should consider enacting reforms in pursuit of this critical goal. We believe that fostering the integration of economic exchanges (12) and enlarging network exchanges (44, 72-74) is one essential solution to a problem which, ultimately, will put a stranglehold on China's future progress. Via this approach, though, the older systems separating people into distinct classes brought up by Confucian philosophy shall be progressively superseded by the old saying that a chain is only as strong as its weakest link.

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Authors' contributions

RP designed the experiment. RP and MC acquired and analysed the data. RP and MC wrote the paper. LS commented on it. RP, MC and LS obtained the research funds.

<u>**Asymmetric use of punishment in socioeconomic segregated societies leads to an unequal distribution of wealth**</u>

Supplementary information

Supplement to Laboratory Methods

English translation of the questionnaire handed to the students at the beginning of the experiment to ascertain their socioeconomic class.

Questionnaire

云南财经大学
YUNNAN UNIVERSITY OF FINANCE AND ECONOMICS
好学笃行 厚德致远

Experiment id number **Gender**

Date of birth **Age** **Major** **Grade**

Which type of school did you attend before YUFE?

Ancestors' province: **Your province, city, city area:**

How many brothers? **How many sisters?**

Ethnicity **Do you believe in divinities?**

Father's job

Mother's job (also specify if housewife)

How many people live in your family house?

How many rooms does your main family house have?

How many houses does your family have?

Do your parents have a University degree?

Are your parents divorced?

Were you a 'left-behind' child?

Do you like the current Chinese government?

Do you practise any sport?

Do you often attend cultural events (reading books, in theatres, museums, cinemas)?

How many contacts do you have on (click) QQ**,** Skype**,** Weibo**,** RenRen**,** WeChat**?**

Do you consider yourself to be good looking?

Do you consider yourself to be self-confident or shyer?

Do you in general have a happy and positive personality?

Notes:

Thanks for your answers!

Reported below are the answers offered by the relevant multiple-choice questions:

- Province: the list of 31 provinces and autonomous entities.
- Ethnicity: the full list of 57 Chinese ethnic groups including "naturalised Chinese".
- Type of school before entering university: Public; Private; Both.
- Your Father's Profession: Public sector, functionary; Public sector, officer; Private sector, entrepreneur; Private sector, manager; Private sector, worker; Looking for a job
- Your Mother's Profession: Public sector, functionary; Public sector, officer; Private sector, entrepreneur; Private sector, manager; Private sector, worker; Housewife; Looking for a job.
- Do your parents have a bachelor's degree: Yes, both do; Only my father; Only my mother; No, both don't.
- Did your parents divorce: Yes; No; Prefer not to say.
- Were you once left-behind child: Yes; No.
- Do you believe in divinities: Yes; No; Hard to say.
- Do you like the current Chinese government: Yes; No; Hard to say.
- Do you like doing some sports in your spare time: Yes; No; Hard to say.
- Do you take part in some cultural activities: Yes; No; Hard to say.
- How many contacts do you have on QQ, (following question) on WeChat (following question) on you phone's contact list: 1-50; 51-100; 101-200; >200.
- Do you consider yourself to be good looking: Yes; No; Hard to say.
- Self-confident or shyer: Shyer; More confident; Hard to say.
- Do you have a positive personality: Yes; No; Hard to say.

Supplement to Agent-Based Models

<u>Model Description</u>

This model description follows the standardized ODD (Overview, Design concepts, and Details) protocol for describing individual and agent based models (Grimm et al. 2006).

<u>Purpose</u>

Here we use an agent-based modeling approach to implement an iterated Prisoner's Dilemma Game (for the complete matrix of payoffs, see Methods of the paper) where agents belong to two different socioeconomic classes. We split the agents into two distinct classes based on their wealth and we gave the capability to only one class to punish the other one. We designed three different scenarios where agents adopt a different cognitive strategy: a traditional *tit-for-tat* strategy, a strategy based on information relative to the *last 10 interactions* and another in which agents can remember the outcomes of *all past interactions*.

State variables and scales

In this model time is represented discretely. Space is not explicitly modeled. In a population of N agents, dyads of agents are selected and play an iterated Prisoner's Dilemma game. During each time period, agents execute the commands described in the schedule, perform one of three possible actions (i.e., depending on their class the action can be cooperation, defection, punishment or only cooperation and defection) and their properties are updated accordingly.

Entity	**State variable**	**Description**
Global	Coop actions	Overall number of cooperative actions performed over the time
	Defection actions	Overall number of defective actions performed over the time
	Punishment actions	Overall number of punishment actions performed over the time
Agents	Memory	The memory agents may use in remembering outcomes of past interactions with the same partner
	Social-status	The social class of origins
	Partner	The current partner each agent is playing against
	Action	The performed action
	Score	The payoff accumulated over the time

Process overview and scheduling

- This model proceeds in discrete time steps, and entities execute procedures according to the following ordering:
- Select dyads of players: agents which are not coupled are selected to form new dyads; in each dyad both

classes are represented (i.e., each dyad is composed by an agent from class 1 and another agent from class 2); each time a new dyad is initialized, a random generated number (random-normal 4 2) indicates the expected number of iterated interaction between agents within the same dyad; however, after each interaction, there is a probability 0.75 that two agents continue to be part of the same dyad. Each agent within the same dyad initializes its own set of interaction-related properties (memory, partner).

- Dyads of players play: players play the Prisoner's Dilemma game adopting one of three possible strategies (tit-for-tat, short-term memory and complete memory of past interactions with the same partner) and their properties are updated accordingly with the outcomes of the game. After each interaction, there is a probability 0.75 that two agents continue to be part of the same dyad (and, of course, a probability 0.25 that they instead change partner).
- Global variables are updated.
- The single model cycle ends.

Design concepts

Emergence:

In this model, one of three possible actions (cooperation, defection and punishment) may emerge as the most adopted by agents from interactions between dyads of agents.

Prediction:

Agents in this model can have the ability to process information gained from past interactions (short-term memory and complete memory of past interactions with the same partner).

Sensing:

Agents play the Prisoner's Dilemma game with their partner simultaneously and are aware of the outcome of the interaction at the end of each one of them.

Interaction:

Agents interact by adopting a cognitive strategy (tit-for-tat, short-term memory or complete memory) performing one of three possible actions (cooperation, defection or punishment).

Stochasticity:

Dyads of agents are randomly initialized at the beginning of each run and when agents change partner over time. When the memory of the agents is empty and they adopt a memory-based strategy, the action to be performed is randomly selected among those available to the agent (cooperation, defection or punishment, depending on the social class of origin).

Observation:

Reported data are averaged from 100 runs. Simulations were run over 80 consecutive interactions.

Initialization

All runs were initialized according to default parameters reported in the table below.

Entity	State variable	Initial/Default value	Units
Global	Coop actions	0	Number of performed actions
	Defection actions	0	Number of performed actions
	Punishment actions	0	Number of performed actions
Agents	Memory	[]	Empty memory
	Social-status	[0,1]	A Boolean value
	Partner	[]	Empty array
	Action	[]	Empty array
	Score	0	Payoff

Input

In order to make our model of the Prisoner's Dilemma Game consistent with experiments performed with human subjects, the distribution of number of consecutive interactions was implemented following (Dal Bó 2005). The population size varied accordingly with Sutcliff et al. (2012) idea that the smaller the population the stronger the ties of the individual belonging to that population network. Therefore, the population size correlates with qualitatively different social relationships.

Parameter	Values
N	5, 15, 50, 150, 350, 1000
Predisposition	Cooperation, Defection
Memory	True, False
If Memory	10, incremental up to 80
Repetitions	100

Parameter	Values
N	5, 15, 50, 150, 350, 1000
Rounds	80
Replicates	100
Propensity of behaving as cooperator or defector	0.7, 0.95
Treatments	T0, T1, T2
Cognitive strategy	Tit-for-tat, short memory, incremental memory
Memory length	5, 10, 80

Algorithm of Tit-for-Tat strategy.

Case of rich agents:
if length of memory = 0
then perform shuffle (c, d)
end
if length of memory > 0
then if last of memory = d, if random 1 > p, then perform p (else d)
if last of memory = c, then perform c
end

Case of poor agents:
if length of memory = 0
then perform shuffle (c, d)
end
if length of memory > 0
then if last of memory = d, then perform d
if last of memory = c, then perform c
if last of memory = p, if random 1 > p, then perform d (else c)
end

Where p is the group dependent propensity in adopting a defective or cooperative strategy.

Supplement to Laboratory Results

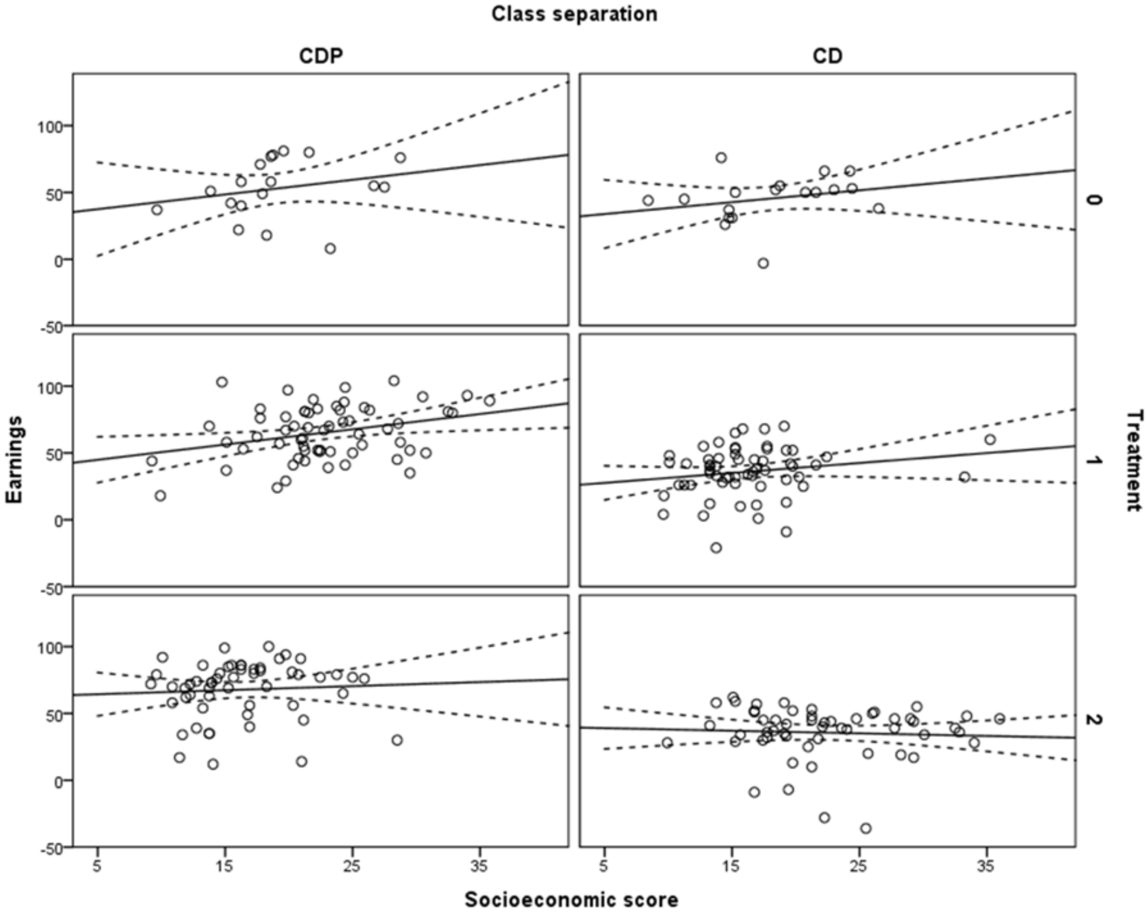

Figure 1. Propensity to earn more due to the originating socioeconomic background. The participants coming from a better off background give evidence for utilising the behavioural strategies more effectively than poorer participants. In T2 this happens less (shown by a less steep intercept line) probably because the richer individuals are disadvantaged not being able to use punishment.

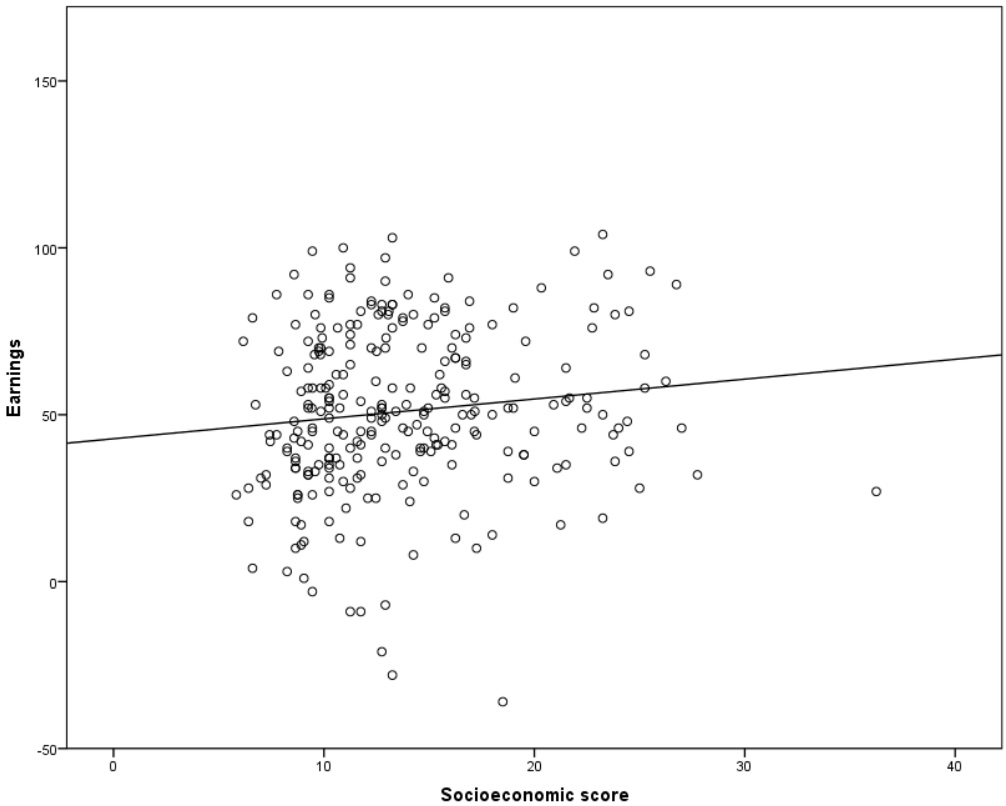

Figure 2. Propensity to earn more due to the originating socioeconomic background. On average, richer participants give evidence for utilising the behavioural strategies more effectively than poorer participants, and they eventually earn more. The values plotted on this graph are the pooled earnings gained by all the participants who took part in the experiments, without treatment distinction.

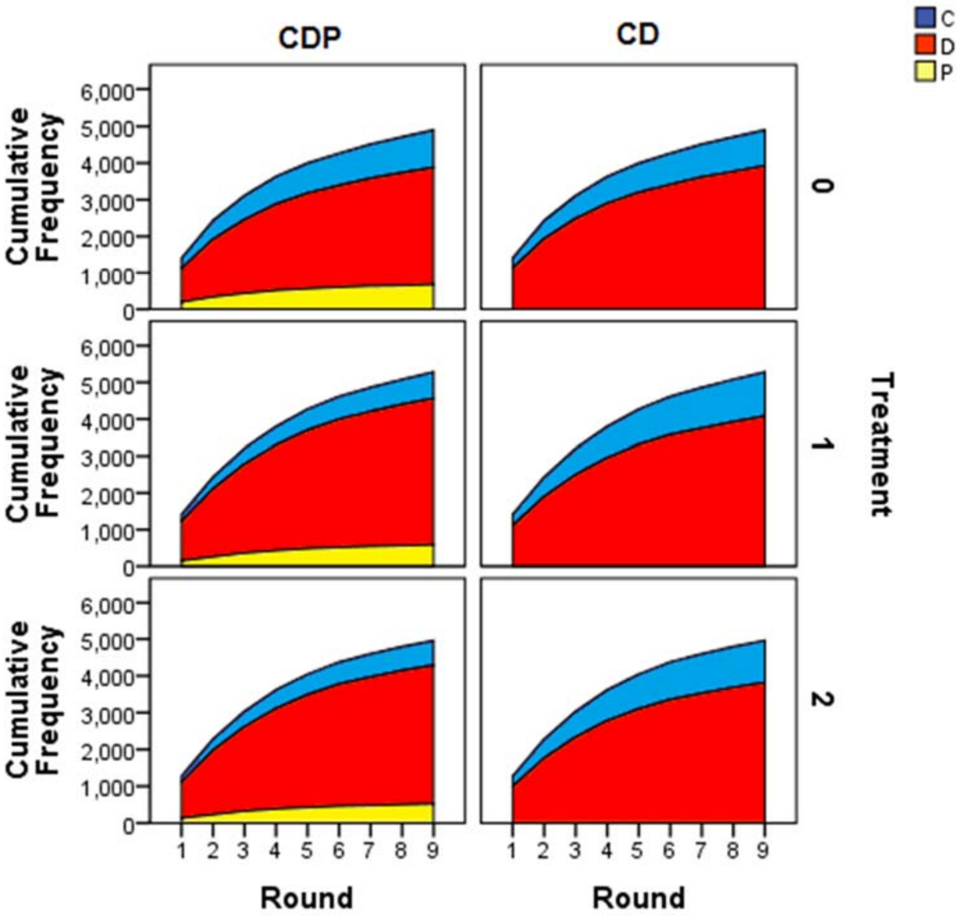

Figure 3. Sequence of behavioural exchanges carried out by the dyads of partners belonging to the two different socioeconomic classes across the three treatments. The time scale is specified in rounds per interaction.

Supplement to ABM Results

DEFECT OR COOPERATE AT 70%

In the first set of simulations we tested a class-dependent predisposition of behaving as a cooperators (for agents from the class of poor agents) or defectors (for agents from the class of rich agents). In this set of simulations, agents have a predisposition to behave according to the class they belong to with a probability of p = 0.7. Across the three treatments, the adoption of a Tit-for-Tat strategy facilitates the emergence and stabilization of cooperation. This is in accordance to what shown in the literature (Nowak & Sigmund 1992). The adoption of a memory-based strategy, instead, facilitates the emergence of different behavioural pattern. A short memory of 10 past interactions in T_1 promotes the same amount of cooperation and defection in both groups. In a different way, in T_2 the short memory of 10 past interactions outcomes promotes the emergence of defection in the group of rich agents and cooperation in the group of poor agents. In T_0 and T_1, the strategy of incremental memory makes the agents perform the same amount of cooperative and defective acts; in T_2 this strategy promotes defection in the group of rich agents and cooperation in the group of poor agents.

These results are robust and do not vary with group size. The only clear effect is the reduction in range of standard deviation. For all the plots originating from these results, see Figures 3-5 in this document.

ALL DEFECT AT 95% AND SHORT MEMORY 10

In the second set of simulations, for both classes we modified the rate of the behavioural predisposition (from $p = 0.7$ to $p = 0.95$) with a predisposition to choose defection.

The results this time show that in T_0 agents behave less cooperatively and more defectively than before when adopting a Tit-for-Tat strategy. However, cooperation is still the most frequent behaviour. In T_0, with agents adopting a strategy of short-term memory relying on the outcomes of the last 10 interactions, the results show a decrease in cooperation and an increase in defection. This time defection is the behaviour performed most often. Finally, in condition T_0 with the incremental memory strategy, we can find almost the same pattern, i.e., increase in defection and decrease in cooperation, but the effects are less pronounced. The same pattern emerges also in treatment T_1 and even more clearly in treatment T_2.

Also in this case, results are robust and there is no strong variation modifying the group size.

ALL DEFECT AT 95% AND SHORT MEMORY 5

See main text. (This is the model that most closely matches the results from the human sample)

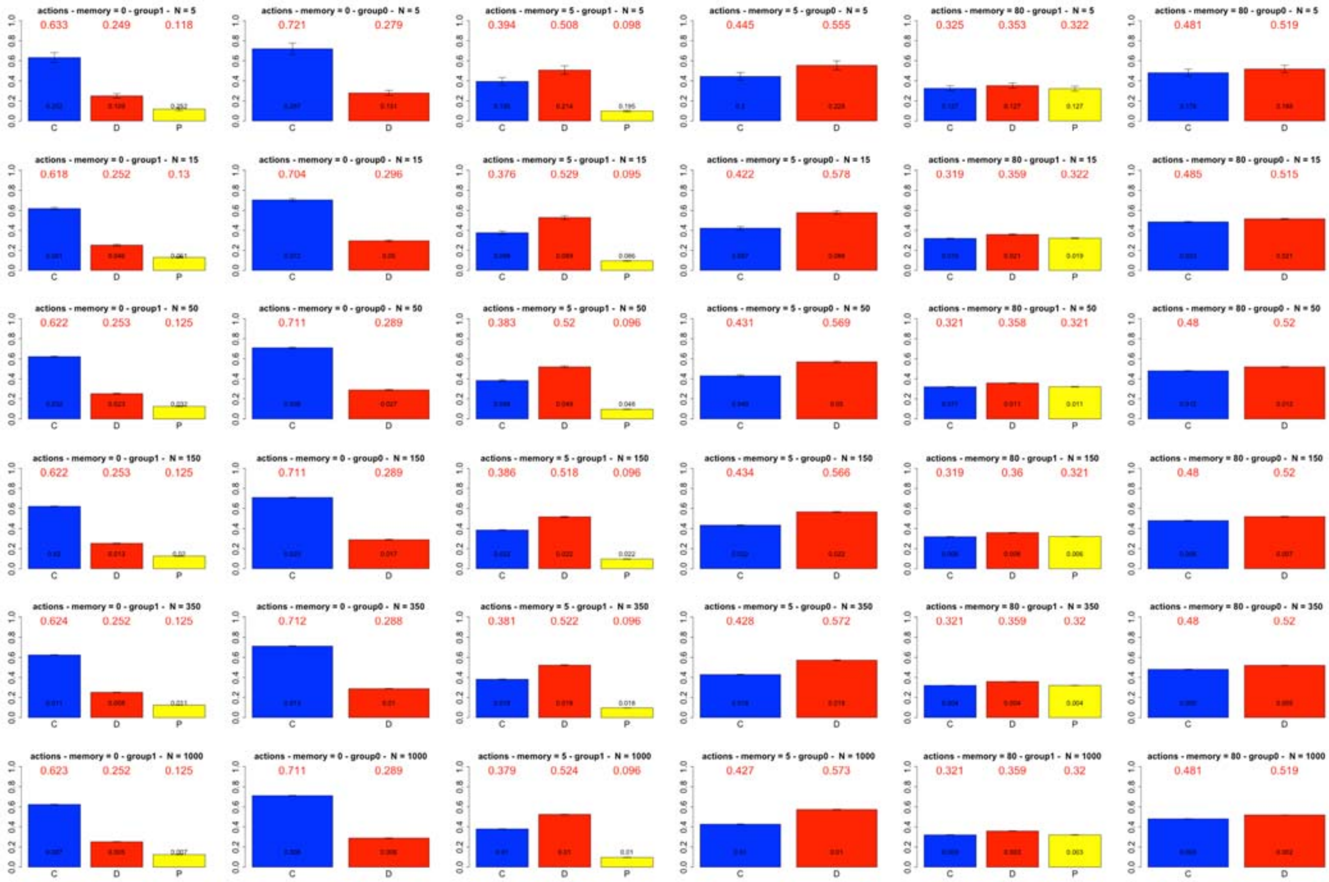

Figure 4. Results from the model with N = {5,15,50,150,350,1000}, T0, propensity of behaving as defector p = 0.95 for agents from both groups. Mean values and 95% confidence interval standard error.

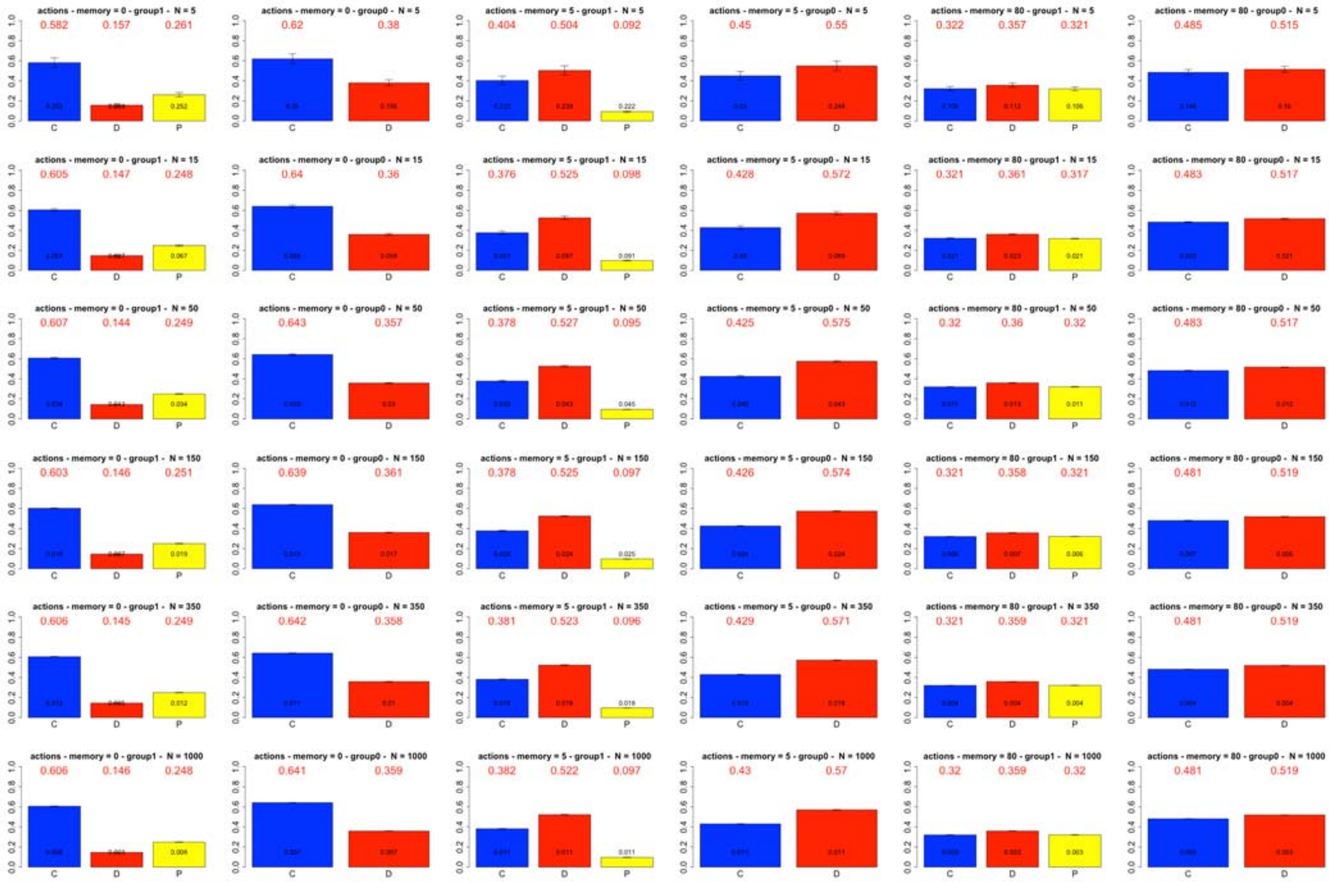

Figure 5. Results from the model with N = {5,15,50,150,350,1000}, T1, propensity of behaving as defector p = 0.95 for agents from both groups. Mean values and 95% confidence interval standard error.

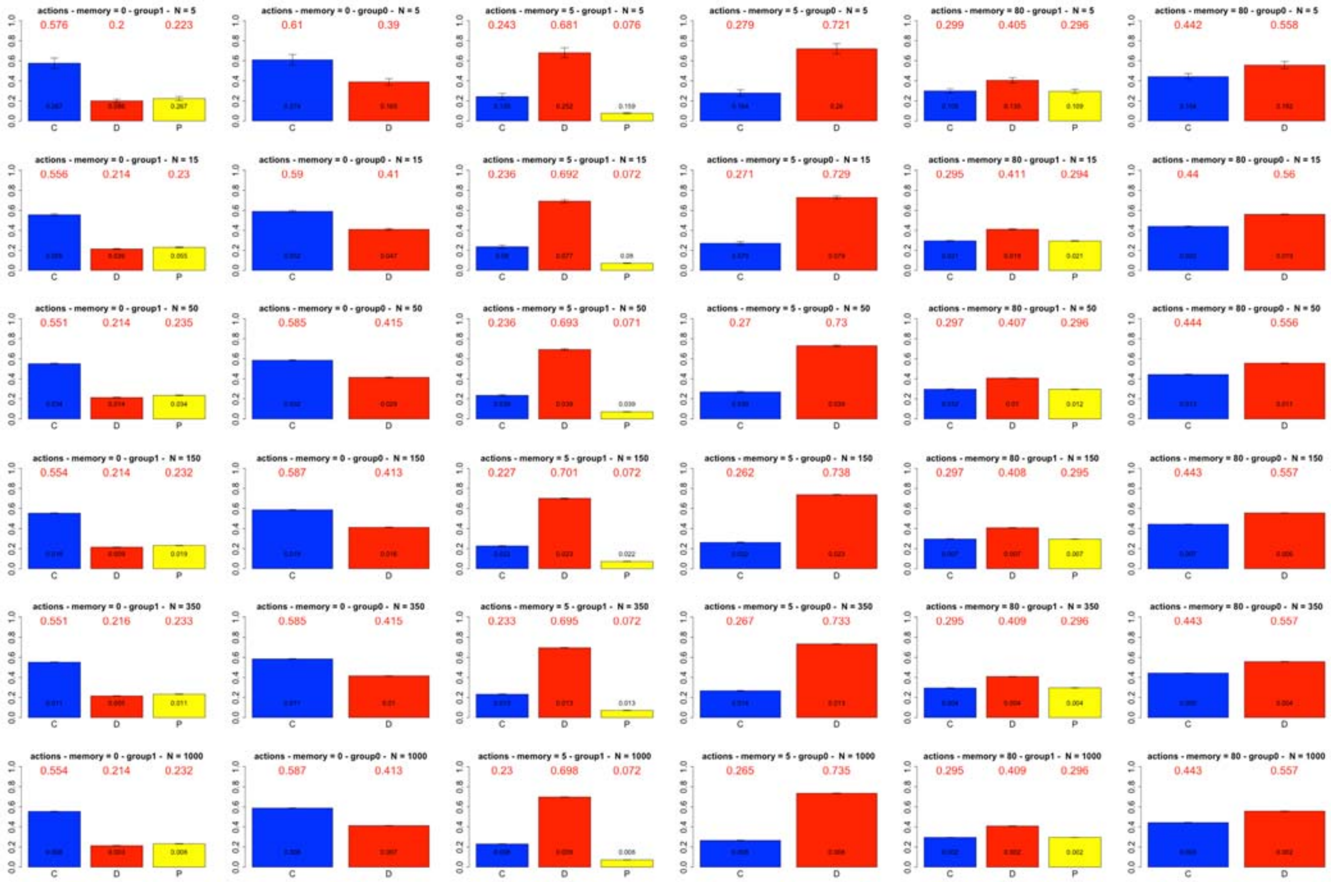

Figure 6. Results from the model with N = {5,15,50,150,350,1000}, T2, propensity of behaving as defector p = 0.95 for agents from both groups. Mean values and 95% confidence interval standard error.

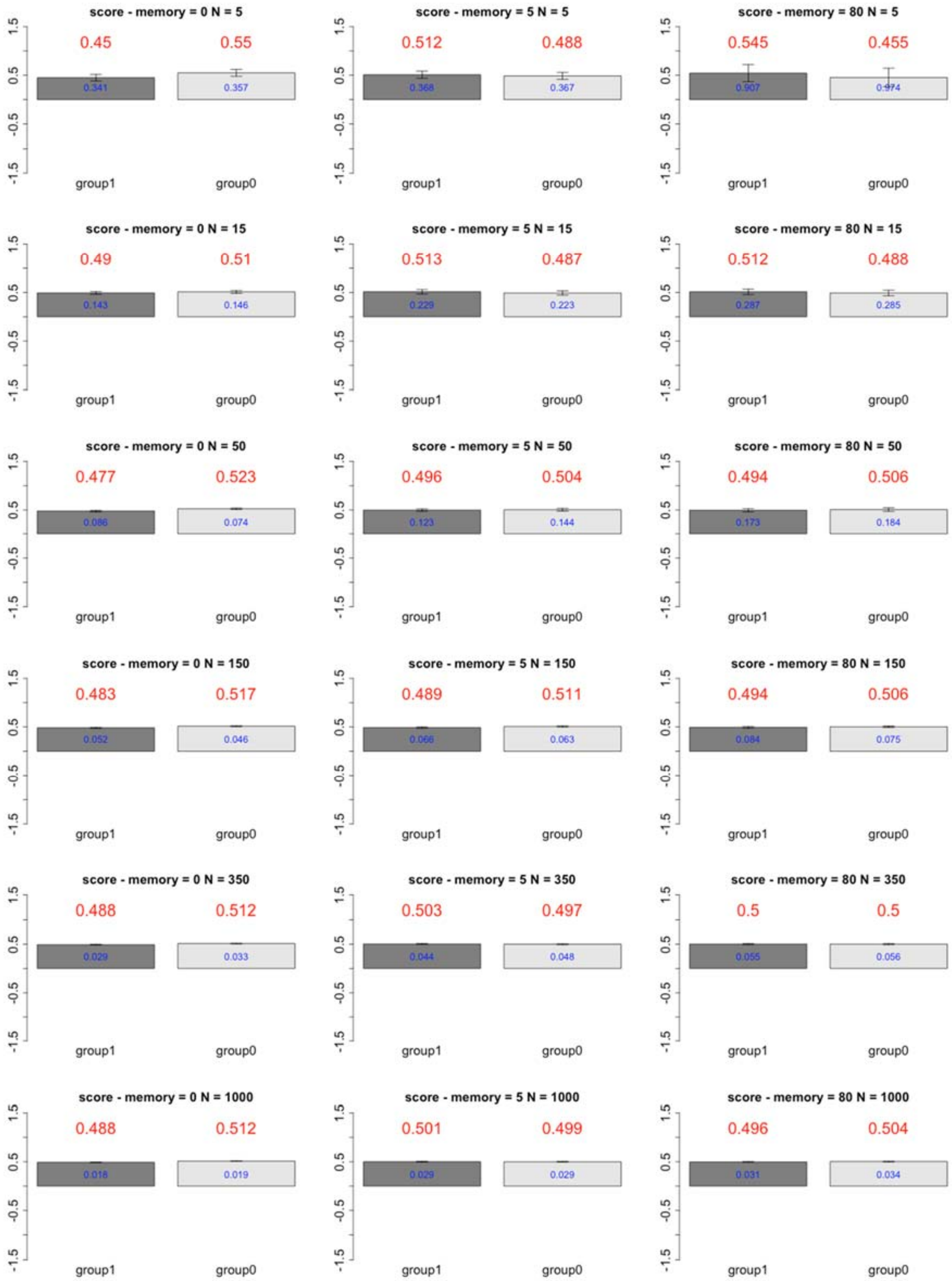

Figure 7. Earning from the model with N = {5,15,50,150,350,1000}, T0, defector p = 0.95 for agents from both groups. Mean values and 95% confidence interval standard error.

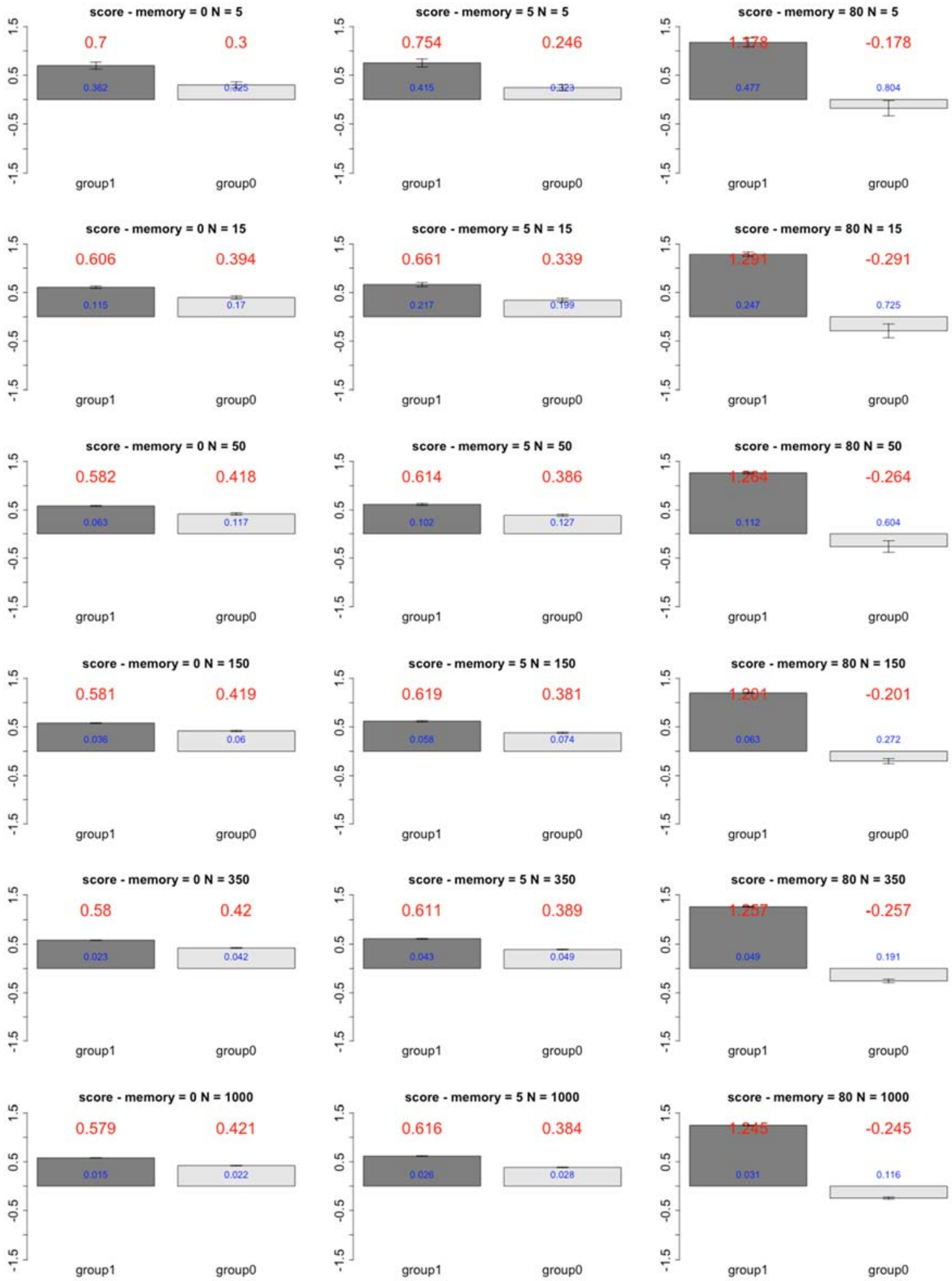

Figure 8. Earning from the model with N = {5,15,50,150,350,1000}, T1, defector p = 0.95 for agents from both groups. Mean values and 95% confidence interval standard error.

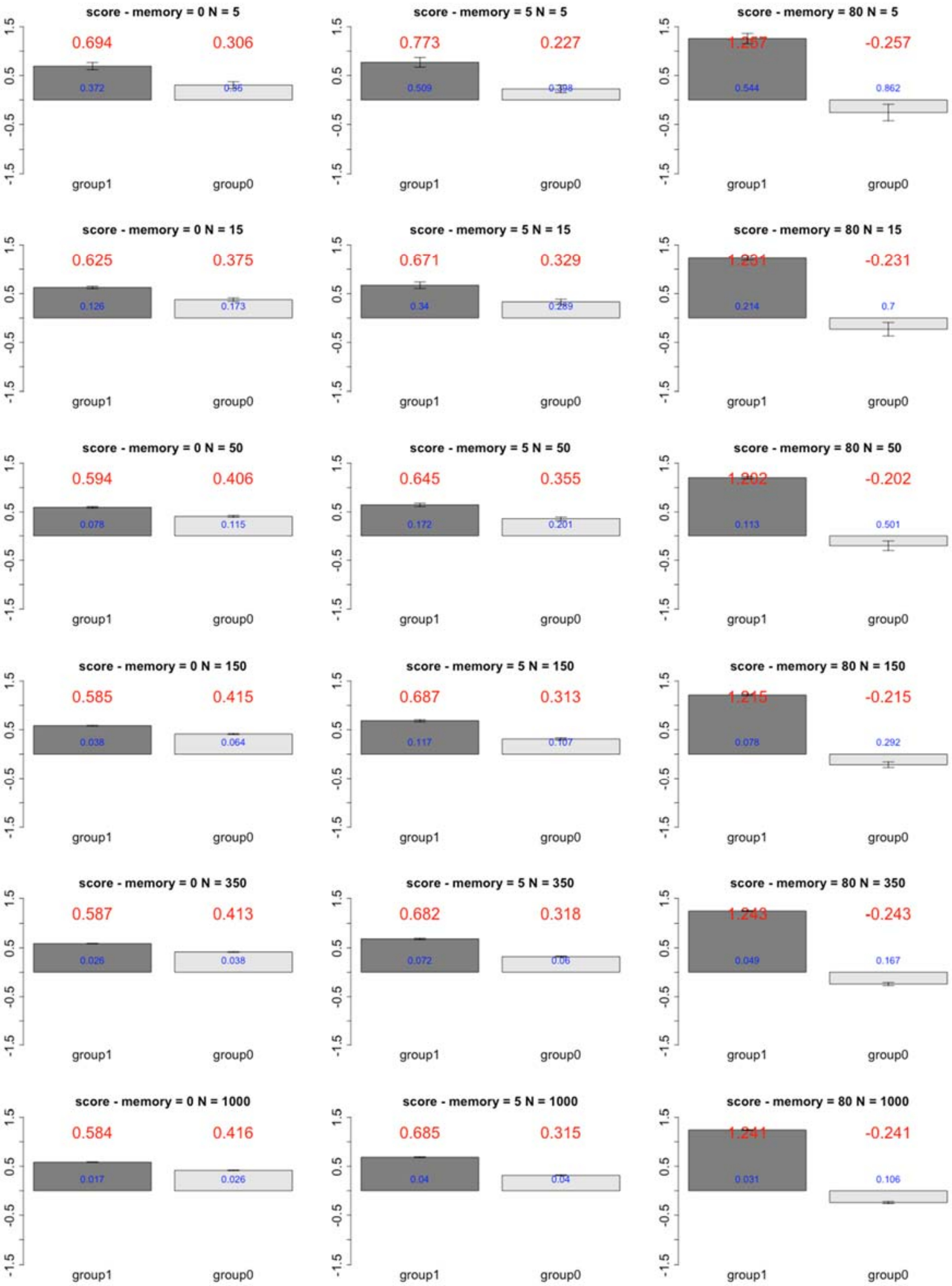

Figure 9. Earning from the model with N = {5,15,50,150,350,1000}, T2, defector p = 0.95 for agents from both groups. Mean values and 95% confidence interval standard error.

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