Cooperative Trends in a Modified Image Scoring Model *

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The evolution of modern cooperative trends now seen in society have not yet been easily explained. After extensive computational studies and theoretical analysis, Nowak and Sigmund proposed that cooperation was established largely due to the emergence of indirect reciprocity. Our previous studies show that a high information flow rate stimulates cooperation in a society. In this study we find that the decrease of cooperation cost will make a society more cooperative, and the inheritance of wealth will induce cooperation in the society even when the exchange rate is comparatively low. We also study the distribution of knowledge according to wealth. We find that, for this model, cooperation is slightly less likely to occur if the exchange rate is low.

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Modern cooperative trends now seen in society are not easily explained, and so far there have been no largely agreed upon explanations of how this came about. There are two major theories that attempt to explain why people cooperate in such a complex way. Genetic kinship theory states that close genetic relations will allow self-sacrifice of one's fitness for the sake of another.[1−3] This theory explains the origins of cooperation rather well and recent studies by Riolo *et al.*[4] have shown that cooperative trends arise when kinship includes other players with similar arbitrary characteristics. Reciprocity is another theoretical explanation of the emergence of cooperation and is simply defined as a mutual exchange of privileges. Direct reciprocity is an exchange between two players (donor and recipient) where repayment to the donor can be given immediately from the recipient. Indirect reciprocity is when the donor expects a return from someone else in the population other than the recipient. The short-term benefit for the donor is low, but the long-term effects of these exchanges can benefit the entire society.

The basis for this study is the image scoring model proposed by Nowak and Sigmund.[5] In the original model, players have a static strategy that defines how cooperative they are as well as an image score that allows other players to evaluate how cooperative that player has been in recent interactions. These values allow players to decide if another player deserves to be given a benefit at a cost to themselves. After many interactions, the players produce offspring and, if a player is wealthy and fit enough to care for them, they are likely to have more offspring than someone who is less fit. After many generations different social patterns begin to form with the more cooperative players dominating the society if conditions permit.

The original work of Nowak and Sigmund did not discuss different factors that influence the state of society, such as the effect of information flow rate, the cost of donor, and the effect of wealth inheritance. We decided to conduct systematic research of these effects. In the previous study, we modified the Nowak and Sigmund model and found that cooperation cannot be established unless the transparency of the society and the exchange rate of information though the society is large enough.[6] In this work, we modify the model again and we focus our study on the effects of inheritance of wealth, the cost of cooperation and the information distribution. We have found that the effects of inheritance of wealth produce an increase in cooperation when both the frequency of exchange between players and the transparency is low; that the increase of the cost of cooperation will introduce a transition from an altruistic society to a selfish society; and that if wealth is inherited and the knowledge of other players is distributed in proportion to wealth, the system has no qualitative changes.

The model used in our previous study considered a society with a population of $n = 100$ players. What occurs in one generation is as follows. All players are initialized with a random strategy value (k) ranging from -5 to $+6$ with each strategy being fairly represented. Each player also has an image score (s) which is set to zero at the beginning of the generation. For each interaction, two random players are chosen as the potential donor and recipient. The donor decides to give a benefit (b) to the recipient at a cost (c) to himself if recipient's image score is greater than or equal to the donor's strategy. If the donor agrees to help, his image score will be increased by 1, while that of the recipient is kept unchanged. On the other hand, if the donor refuses to help, his image score will be

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decreased by 1. Throughout the time of the generation, players' image scores are allowed to range from -5 to $+5$. The transparency (q) of the society determines the player's probability that he will witness an interaction between two other group members, therefore giving him more information upon which to base his decision. In each generation (t) the frequency of exchange (f) determines the total number of interactions among the players, which is fn. The average number of interactions per generation is therefore $2f$. Increasing the amount of interactions does increase the chance that a player will meet another player in the population more than once. If that situation occurred too often, direct reciprocity would be partially responsible for the outcome of a cooperative or non-cooperative society. The chances of a player meeting another player again, however, are still negligible even for $f = 7$. Therefore, only indirect reciprocity emerges from the interactions of the players.

After each generation, players produce offspring in proportion to their wealth. After many generations (150 generations is used in this study), we can calculate the percentage of cooperative players in the society (w). Then, to obtain an accurate representation these 150 generations are calculated 500 times.

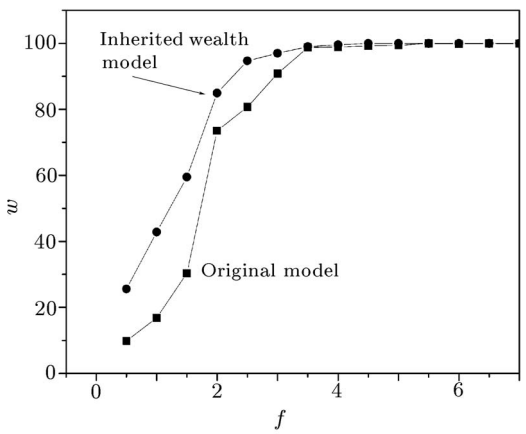


Fig. 1. Percentage of cooperative players (w) versus f in the image scoring indirect reciprocity model. When wealth is inherited, cooperation becomes much more likely to occur for lower values of f. In this numerical calculation: $q = 1.0$, $b = 1.0$, $c = 0.1$, and $t = 150$.

If we look critically at this model, it is seen that the society cannot become completely cooperative unless q is approximately 0.5. In other words, half of the population must witness each donor/recipient interaction before a stable cooperative society emerges. In a real society, half of the population would probably not be required to reach a stable position. To compensate for this inconsistency, we carried out the following modification to the original model. Instead of just the strategy of an ancestor being inherited by the offspring, their wealth should also be inherited. The wealth is not divided up among the offspring in this simulation because wealth can be thought of as the health of a player and his ability to reproduce. Genetically speaking, this trait would not be distributed among his children but would be totally inherited by each child.

Looking at the results when f is varied, the same trend occurs that took place without wealth inherited. As seen in Fig. 1, the inheritance of wealth makes the society more cooperative. This new feature of gene flow seems to make a relatively large difference in the outcome of a society when f is small. When cooperator's initial wealth is inherited, his chances of survival are much higher and his need to gain access to information is much lower thereby inducing cooperation in the society more easily.

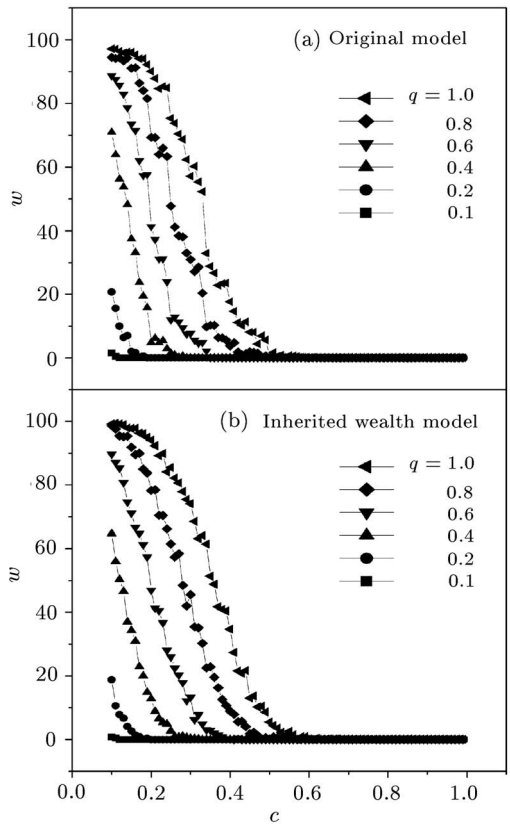


Fig. 2. (a) Varying the cost from 0.1 to 1.0, the percentage of cooperative players decreases rapidly for all values of q. (b) Even with the inheritance of wealth included in this model, there is no chance of cooperation beyond the value of $c = 0.5$. In both numerical calculations, q ranges from 0.1 to 1.0, $b = 1.0$, and $t = 150$.

Next, we study the effect of the cost of cooperation on the state of a society using the image scoring model. Setting $f = 4.0$, $b = 1.0$ and varying the cost factor, we see from Fig. 2(a) that as the cost rises, w decreases quickly. With the cost of cooperation so high, the cooperative players do not gain enough of an advantage to dominate the group. The defectors do much better

by exploiting unconditional helpers ($k < 0$) or by simply avoiding any interactions. The result when wealth is inherited is no different. Though the cooperators are building upon their inherited wealth, it does not give an even noticeable advantage to them. Even if the society is totally transparent ($q = 1.0$), the number of cooperative players goes to zero at the c/b ratio of $1/2$.

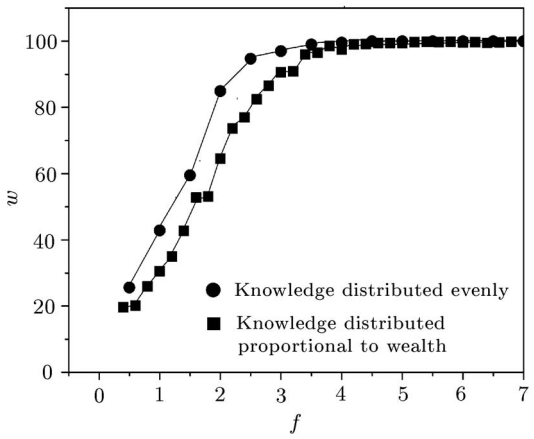


Fig. 3. Distributing knowledge about other players in a society yields similar results. As f increases to 7.0, w increases nearly at the same rate for both distributions of knowledge. In this numerical calculation, $q = 1.0$, $b = 1.0$, $c = 0.1$, and $t = 150$.

The simulations thus far have assumed that the knowledge about the other players (q) was distributed evenly over the population. It is likely, however, that the availability of resources should make it possible for the players to know more about the other players in the society. Updating the value of q for each player after each interaction so that it is made proportional to a player's wealth creates a Gaussian distribution of knowledge in the population. Our simulation shows that by increasing the amount of total information available to the society (10–100%), the resulting rate of achieving cooperation is very similar to that when knowledge is evenly distributed. This is easily seen from Fig. 3. For small values of f, some noticeable differences do occur however. For instance, when $f = 2$, $w = 80\%$ if knowledge is distributed evenly. If knowledge is distributed proportional to wealth, however, when $f = 2$, $w = 50\%$.

Darwin's basic premises state that species do not live in just one state of existence, but exist in unending states of change. These states of change are what allow a socially centred species such as humans to develop. By using simple concepts for the basis of human interaction, indirect reciprocity is seen to emerge as a driving force towards establishing a cooperative society. The indirect reciprocity model which has been the discussion of many recent papers shows its ability to withstand perturbations and has explained modern cooperative trends fairly successfully.[5−7] By including the inheritance of wealth in this study, cooperation is stimulated more easily especially as the flow of information decreases. If the amount of knowledge available to a player is made proportional to his wealth however, it is more difficult for cooperation to occur. Further paths of study which may test the indirect reciprocity theory include studying the patterns of cooperation that occur as the population size increases or examining the distributed knowledge model as the cost of cooperation increases. Recent work by Leimar *et al.*[8] also suggests some shortcomings of the image scoring model, such as genetic drift, that may also be considered in further studies.

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